Doc 9938, CAEP/8

INTERNATIONAL CIVIL
AVIATION ORGANIZATION

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

EIGHTH MEETING

Montréal, 1–12 February 2010

REPORT

Approved by the Committee on Aviation Environmental Protection and published by decision of the Council.

The views expressed in this report should be taken as advice of a body of experts to the Council but not as representing the views of the Organization.

The Supplement to the report indicates the action taken on the report by the Council.

MONTRÉAL 2010

Doc 9938, CAEP/8

INTERNATIONAL CIVIL
AVIATION ORGANIZATION

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

EIGHTH MEETING

Montréal, 1–12 February 2010

REPORT

Approved by the Committee on Aviation Environmental Protection and published by decision of the Council.

The views expressed in this report should be taken as advice of a body of experts to the Council but not as representing the views of the Organization.

The Supplement to the report indicates the action taken on the report by the Council.

MONTRÉAL 2010

Published in separate English, Arabic, Chinese, French, Russian
and Spanish editions by the
INTERNATIONAL CIVIL AVIATION ORGANIZATION
999 University Street, Montréal, Quebec, Canada H3C 5H7

For ordering information and for a complete listing of sales agents
and booksellers, please go to the ICAO website at www.icao.int

Doc 9938, ***Committee on Aviation Environmental Protection, Eighth Meeting***
Order Number: 9938
ISBN 978-92-9231-588-7

INTERNATIONAL CIVIL AVIATION ORGANIZATION

EIGHTH MEETING OF THE
COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

Montreal, 1 to 12 February 2010

SUPPLEMENT NO. 1

1. The Council, at the 4th meeting of its 190th Session on 25 May 2010, took action on the recommendations of the eighth meeting of the Committee on Aviation Environmental Protection (CAEP/8), as set forth hereunder.

2. RECOMMENDATIONS FOR AMENDMENT OF STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES (RSPP)

2.1 Recommendation 2/2, page 2-15
Recommendation 4/1, page 4-4

2.2 The Council agreed that the above recommendations should be referred to Contracting States and international organizations. Following receipt of comments, the Air Navigation Commission will conduct a detailed review and will then present its recommendations for action to the Council.

3. RECOMMENDATIONS OTHER THAN FOR STANDARDS AND RECOMMENDED PRACTICES AND PROCEDURES

3.1 The Secretary General will arrange for any follow-up action in respect of all approved recommendations as indicated in the action taken hereunder.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
1/1	1-39	C	**Acceptance of the global environmental trends assessments** Approved the recommendation and requested the Secretary General to take the necessary action.
1/2	1-42	C	**Publication of "Report of the Independent Experts on NO_X Reduction Technologies Review and the Associated medium and Long Term Goals"** Approved the recommendation and requested the Secretary General to take the necessary action.
1/3	1-44	C	**Publication of "Report of the Independent Experts on Noise Reduction Technologies Review and the Associated Medium and Long Term Goals"** Approved the recommendation and requested the Secretary General to take the necessary action.
1/4	1-48	C	**Review of fuel burn reduction technologies by a panel of independent experts to establish medium- and long-term technology goals for fuel burn reduction** Approved the recommendation and requested the Secretary General to take the necessary action.
2/1	2-5	C	**Publication of the Environmental Technical Manual, Volume II** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
2/3	2-17	C	**Fuel efficiency and CO_2 emissions metrics** Approved the recommendation and requested the Secretary General to take the necessary action.
2/4	2-38	C	**Update to *Airport Air Quality Guidance Manual* (Doc 9889)** Approved the recommendation and requested the Secretary General to take the necessary action.
2/5	2-40	C	**Report on Environmental Management Systems Practices in the Aviation Sector** Approved the recommendation and requested the Secretary General to take the necessary action.
3/1	3-2	C	**Publication of the updated Report on Voluntary Emissions Trading for Aviation** Approved the recommendation and requested the Secretary General to take the necessary action.
3/2	3-3	C	**Publication of the Scoping Study of Issues Related to Linking Open Emissions Trading Systems Involving International Aviation** Approved the recommendation and requested the Secretary General to take the necessary action.
3/3	3-5	C	**Publication of the Scoping Study on the Application of Emission Trading and Offsets for Local Air Quality in Aviation** Approved the recommendation and requested the Secretary General to take the necessary action.

Report Reference		Action by Council (C) or Air Navigation Commission (ANC)	Recommendation Title and Action Taken
Recommendation No.	Page No.		
3/4	3-6	C	**Publication of the Report on Offsetting Emissions from the Aviation Sector** Approved the recommendation and requested the Secretary General to take the necessary action.
3/5	3-7	C	**Publication of information on voluntary measures** Approved the recommendation and requested the Secretary General to take the necessary action.
4/2	4-6	C	**Publication of Environmental Technical Manual, Volume I** Approved the recommendation and requested the Secretary General to take the necessary action.
4/3	4-24	C	**Amendment to the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829)** Approved the recommendation and requested the Secretary General to take the necessary action.
4/4	4-28	C	**Amendment to the *Review of Noise Abatement Procedure Research and Development and Implementation Results* (Doc 9888)** Approved the recommendation and requested the Secretary General to take the necessary action.
5/1	5-7	C	**Revised CAEP Work Programme** Approved the revised work programme.

— — — — — — — —

EIGHTH MEETING OF THE
COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)
(2010)

LETTER OF TRANSMITTAL

To: President of the Council

From: Chairman, Committee on Aviation Environmental Protection (CAEP) (2010)

I have the honour to submit the report of the eighth meeting of the Committee on Aviation Environmental Protection (CAEP) which was held in Montréal from 1 to 12 February 2010.

Chairman

Montréal, 12 February 2010

TABLE OF CONTENTS

LIST OF RECOMMENDATIONS*

* Recommendations annotated "RSPP" relate to proposals for amendment of Standards, Recommended Practices and Procedures for Air Navigation Services or guidance material in an Annex.

COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION (CAEP)

EIGHTH MEETING

Montréal, 1 to 12 February 2010

HISTORY OF THE MEETING

1. DURATION

1.1 The eighth meeting of the Committee on Aviation Environmental Protection (CAEP/8) was opened by the First Vice President of the ICAO Council, in Montréal, at 0930 hours, on 1 February 2010. The meeting ended on 12 February 2010.

2. ATTENDANCE

2.1 The meeting was attended by Members and Observers nominated by 25 Contracting States and 10 International Organizations, as well as by advisers and others as shown in the list below :

Members	Advisers	State
A.M. Singh	S. Prado	Argentina
D. Southgate	T. Milczarek	Australia
J. Silveira	A. Romera M. Saito A. Filizola R. Carvalho	Brazil
G. Bourgeois	T. McDonald A. Simpson S. Mallet Y. Cousineau F. Viele T. Lowrey M. Kerr-Upal J. Hull S. McKibbon M. Manzo L. Aalders K. McCaldon B. Boucher W. Bailey C. Blain	Canada

Members	Advisers	State
	I. Trépanier L. Knaapen R. Mcgill G. Rusnak J. Mcdonald A. Ermakov D. Weber J. Johnston	
L. Xiaojie	F. Tai M. Yang A. Fung R. Wang B. Yang G. Yan	China
M. M. El-Hakim		Egypt
P. Langumier	A. Depitre M. Millischer D. Cario	France
F. Pleines-Schmidt	M. Dieroff F. Wetzel J. Scheelhase	Germany
R. Cecchi	G. Di Gregorio F. Sepe	Italy
A. Matsui	T. Shimizu M. Nishitani H. Hashimoto S. Tachibana T. Yamamoto Y. Makino H. Ishii K. Nii T. Sasaki	Japan
G. Bekebrede	H. Pulles M. Lunter	Netherlands
S. O. Dawuda	P. Alawani	Nigeria
T. Reklewski	A. Rode	Poland

Members	**Advisers**	**State**
S. Volkov	Y. Khaletskiy O. Kartyshev V. Kopiev	Russian Federation
H.Seng Looi	L. Xian Koh T.Chiang Neo	Singapore
K. Sim		South Africa
A. Iglesias Sastre	A. de Benito E. Pascual Albarracín	Spain
K. Keldusild	T. Sjöberg K. Lohko A. Lindell J. Larsson	Sweden
U. Ziegler	C. Marthe	Switzerland
O. Zaporozhets		Ukraine
J. Hotchkiss	R. Worth D. Lister D. Lee C. Eyers S. Baker N. Cumpsty M. Ralph	United Kingdom
L. Maurice	R. Girvin J. Marks C. Holsclaw G. Fleming M. Spears P. Gliebe K. Edwards C. Grundler	United States

Observers	Advisers	State/Organization
A. Kokkinos		Greece
T. Krakenes	J. Paulsen J. Ditlevsen	Norway
	A. Teffaha	ACAC
X. Oh	E. Fleuti E. Leavitt I. Cornier J. Steinhilber	ACI
I. Jopson		CANSO
D. Batchelor	A. Melrose S. Arrowsmith W. Franken T. Elliff	EC
A.Hardeman	T. Roetger M. Comber A. Robinson D. Thompkins K. Welsh B. Hawkins N. Young Le Thi Mai G. Morse R. Brown P. Jensen C. Schroeder S. Tedrow J. O'Brien	IATA
R. Gage	R. Shuter E. Cotti P. Ingleton J-C. Gallagher	IBAC
D. Allyn	P. Fonta K. Morris S. Mertes H. Aylesworth O. Husse P. Lempereur P. de Saint Aulaire W. Conley B. Solaimani M. Huising	ICCAIA

B. Pang
J. Bonnet
G. Faeire
C. Grandi
S. Csonka
W. Dodds
R. Majjigi
J. G. Yu
C. Etter
K. Orth
R. Dudebout
T. Oishi
H. Moriai
T. Takami
C. Baltas
L. Gray
D. Sepulveda
G. Girard
P. Madden
E. Jacobs
K. Iijima
J-M. Boiteux
D. Collin
C. Courtet
P. Bendana
M. Heijl
H. Gagnon
F. Viscotchi
J. Lye
S. Davis-Mendelow

T. Johnson	D. Rutherford	ICSA
R. Brons		IFALPA
F. Vladu		UNFCCC

The meeting was also attended by:

D. Jimenez Hernandez Alternate Representative of Mexico on the Council of ICAO

3. OFFICERS AND SECRETARIAT

3.1 Dr. U. Ziegler (Switzerland) was elected Chairman of the meeting and Mr. D. Southgate (Australia) was elected Vice-Chairman of the meeting. The Secretary of the meeting was Mrs. J. Hupe, assisted by Dr. E. Jahangir, Mr. T. Tanaka, Mr. T. Thrasher, Mr. A. Sainarayan and Ms. C. Alves Rodrigues, of the Environment Branch, Air Transport Bureau. Also participating in the meeting were Ms. N. Teyssier, of the Economic Analyses and Policy Section, Air Transport Bureau; Mr. S. da Silva, Air Navigation Bureau, and Mr. Benoit Verhaegen, Legal Bureau.

4. LANGUAGES

4.1 Interpretation and translation were provided in Arabic, Chinese, English, French, Russian and Spanish.

5. AGENDA

5.1 The Council approved the following agenda for the meeting:

Agenda Item 1: Review of the assessments of the present and future impact of aircraft noise and engine emissions;

Agenda Item 2: Review of technical proposals relating to aircraft engine emissions;

Agenda Item 3: Review of market-based measures relating to aircraft engine emissions;

Agenda Item 4: Review of proposals relating to aircraft noise; and

Agenda Item 5: Future work.

6. TERMS OF REFERENCE

6.1 To undertake specific studies, as approved by the Council, related to control of aircraft noise and gaseous emissions from aircraft engines.

6.2 In its work the Committee shall take into account the following:

a) effectiveness and reliability of certification schemes from the viewpoint of technical feasibility, economic reasonableness and environmental benefit to be achieved;

b) developments in other associated fields, e.g. land use planning, noise abatement operating procedures, emission control through operational practices, etc.;

c) international and national programmes of research into control of aircraft noise and control of gaseous emissions from aircraft engines; and

d) the potential interdependence of measures taken to control noise and to control engine emissions.

7. WORK PROGRAMME

7.1 The Committee's work programme for this cycle was agreed during the CAEP/7 meeting and adjusted during the subsequent Steering Group meetings to accommodate the requests of the 36th Session of the ICAO Assembly and of the Group on International Civil Aviation and Climate Change (GIACC). The following tables reflects the updated work programme:

Table 1. Forecasting and Economic Analysis Support Group (FESG)

Group	Item	Description
FESG	F.01.1	Produce a new traffic and fleet forecast over a 30 year time horizon.
FESG	F.01.2	Consider developing an approach to do projections to 2050.
FESG	F.03	Review of APMT for CAEP acceptance [Aviation environmental Portfolio Management Tool]. Sample problem cost-benefit analysis
FESG	F.05	1. Conduct an economic analysis of the financial impact of including international aviation in existing trading schemes. 2. Undertake a literature review of cost-benefit analysis of existing trading systems with a special emphasis on how it has been applied to other sectors in order to draw some pertinent lessons learned for the aviation sector. The study review should identify, as far as possible, the effects on developing countries and where this is not possible, record it.
FESG	F.06	Examine and reconcile, if appropriate, the differences between the 2006 baseline data in the MODTF Common Operations Database (COD) and the baseline data in the FESG fleet forecast.
FESG	F.07	Perform a cost-effectiveness analysis of potential NO_X stringency options.
FESG	F.08	Conduct appropriate analysis on the projected number of engines that will not meet the CAEP/6 engine NO_X Standards and reasons why any in-production engines remain non-compliant.
FESG	F.09	Conduct a scoping analysis of the in-production engines that would be impacted by a potential production cut-off.
FESG	F.10	Coordinate with CAEP Secretary on future requests from GIACC to group.

Table 2. WG1 – Noise Technical Issues

Group	**Item**	**Description**
WG1	N.01	Coordinate with WG3 Rapporteur on the WG1-WG3 Technology Interdependencies Group.
WG1	N.02	Coordinate with WG3 Rapporteur on programme schedules for development of both noise and emissions SARPs for future supersonic aeroplanes.
WG1	N.03	Coordinate with other working group Rapporteurs as necessary.
WG1	N.04	Investigate any other technical issues brought to the attention of the WG and if appropriate propose to add these to the work program.
WG1	N.05	Further develop and monitor the use of guidelines for providing helicopter data for Land-use Planning (LUP) purposes.
WG1	N.06	Investigate adoption of current subsonic noise rules for supersonic Standards and make recommendations as appropriate.
WG1	N.07	Monitor, and report on, status of Supersonic Transport (SST) projects and expectations for their operation (nature, frequency etc.).
WG1	N.08	Monitor, and report on, research to characterize, quantify and measure (including metric) sonic boom signatures, and their acceptability.
WG1	N.09	Assess the extent of knowledge on sonic boom and decide if it is appropriate to consider drafting Standards for sonic boom.
WG1	N.10	Reassess Terms of Reference for work on supersonic task.
WG1	N.11	Provide advice on and assess as necessary any noise related technical questions that may arise from the inter-dependency work.
WG1	N.12.1	Technology interdependencies: Provide the necessary inputs to-MODTF and FESG to integrate technology responses and trade-offs into the CAEP benefit-cost modelling.
WG1	N.13	Consider how best to support development of models used to populate future fleets and the replacement of retired aircraft. In this context review adequacy and update, if necessary, “Best practice database” (bearing in mind purpose, selection criteria, validation and coordination with emissions database).
WG1	N.14	Monitor SAE work to update the atmospheric absorption procedure and assess the impact, including the effect on stringency, of its adoption in the Annex. Make any recommendation that may be appropriate.
WG1	N.15.1	Investigate improvements in guidance within Annex 16, Vol. I, Appendix 2, Section 2.3 on Flight Path Definitions, Measurement Instrumentation and Procedures, and Time-Space-Position Information (TSPI) Data Reduction and Analysis.
WG1	N.15.2	Investigate improvements in guidance within Annex 16, Vol. I, Appendix 2, Section 4 on the Calculation of Effective Perceived Noise Level (EPNL).
WG1	N.15.3	Investigate improvements in guidance within Annex 16, Vol. I, Appendix 2, Sections 8 and 9 on the Adjustment of Aircraft Noise Data to Reference Conditions Using the Simplified and Integrated Methods.
WG1	N.15.4	Investigate improvements in guidance within Annex 16, Vol. I, Appendix 2, Section 6 Nomenclature: Symbols and Units.
WG1	N.15.5	Investigate improvements in guidance within Annex 16, Volume I, Appendix 2, Section 2 on the measurement and characterization of the effect of atmospheric absorption on sound propagation.

Group	**Item**	**Description**
WG1	N.15.6	Investigate improvements in guidance within Annex 16, Volume I, Appendix 2, Section 2 for miscellaneous technical issues and editorial errors.
WG1	N.16.1	Clarify the intent of the applicability language of Annex 16, in respect of the appropriate amendment level of Volume I and revision of ETM (including the acceptability of equivalent procedures) when applied to: a) Applications for Type Certificate (TC) approval to states other than the state of design (after approval by State of Design); b) Applications for amended TCs (type design change) to State of Design and states other than the State of Design; and c) Applications for Supplemental Type Certificate (STCs) to State of Design and states other than the State of Design.
WG1	N.16.2	With regard to all the above consider the definition of "derived version" (particularly *Note 1* and the link with airworthiness regulations) [in the context of commonly used terms such as "major/minor modifications", the "changed product rule" "acoustical change", and "supplemental type certificates"].
WG1	N.16.3	To ensure that applicability language is appropriate to all Chapters of the Annex.
WG1	N.17	Review SAE Aerospace Recommended Practice-ARP1846, Measurement of Far Field from Gas Turbine Engines During Static Operation, identify deficiencies, and means of resolution (e.g. WG1 or A-21).
WG1	N.18	Investigate reference take-off speed definition Part/CS 23 jet aircraft.
WG1	N.19	Identify any changes to Annex 16 that may be necessary to enable the certification of variable systems and to develop possible supplemental schemes to credit their enhanced performance in operation.
WG1	N.21.1	Complete integration of texts and other information from approved and available resources into drafts of New Environmental Technical Manual (ETM) Chapters consistent with WG1 Approved Table of Contents.
WG1	N.21.2	Develop new material and revisions to existing material as considered necessary by WG1 (including review and possible use of available Appendix H & J material developed for AC36-4).
WG1	N.21.3	Continue developing the New Environmental Technical Manual: Liaise with ICAO Secretariat to expedite its publication.
WG1	N.22	Develop acoustical change analysis guidance for small propeller driven aeroplanes under Chapter 10 that have gone through a modification such as a different blade count propeller, weight change and/or drag change.
WG1	N.23	Develop guidance for applicants and authorities on deriving certificated noise levels by interpolation between already approved noise/mass values.
WG1	N.24	Provide a report to CAEP/8 on the results of a review and analysis of certification noise levels for subsonic jet and heavy propeller-driven aeroplanes to understand the current state-of-the-art of aircraft noise technology.
WG1	N.25	Monitor the process for updating the ICAO noise certification database.
WG1	N.26	Update and extend the ICAO noise certification database.
WG1	N.27	Monitor and report on the various national and international research programme goals and milestones.

Group	Item	Description
WG1	N.28	Taking into account the work of Item N.27 (monitor and report on research) and, in coordination with WG3, provide advice and information on mid and long - term noise reduction technology prospects and future trends.
WG1	N.29	Using the independent expert process, with the assistance and cooperation of other bodies of the Organization and of other international organizations, to examine and make recommendations for noise, with respect to aircraft technology and air traffic operational goals (aspects that relate to aircraft based technologies) in the mid term (10 years) and the long term (20 years).
WG1	N.30	To consider alignment with WG3 on using the Technology Readiness Level (TRL) concept for defining of technological feasibility for short term Standard setting and medium/long term technology goals.
WG1	N.31	To provide information on aviation metrics for support of the World Health Organization (WHO) task on an evidence review of aircraft noise and health.
WG1	N.32	Update the text on the equivalent procedure in the ETM on the determination of lateral noise certification levels of jet aeroplanes in order to more precisely describe the accepted method.
WG1	N.33	Coordinate with CAEP Secretary on future requests from GIACC to the Group.

Table 3. WG2 – Operations

Group	Item	Description
WG2	O.00.1	Coordination on Noise Abatement Procedures and ATM WG2 TGs: 2 & 3 External Groups: ANC, OPSP, OCP, FPLSG
WG2	O.00.2	Coordination on far-out approach noise problem in relation to noise certification scheme WG2 TGs: 3 External Groups: WG1
WG2	O.00.3	Coordination in relation to development of air quality guidance WG2 TGs: 4 External Groups: WG3
WG2	O.00.4	Coordination in relation to Noise Abatement Procedures (NAP) and CNS/ATM benefits WG2 TGs: 2 & 3 External Groups: MTF
WG2	O.00.5	Coordination in relation to time-in-mode WG2 TGs: 4 External Groups: FESG & MTF
WG2	O.00.6	Coordination in relation to Airport Air Quality Guidance WG2 TGs: 4 External Groups: SAE
WG2	O.01	Review and updating of the Balanced Approach (BA) guidance to account for policy developments in aspects of CAEP's work that necessitates updating of the guidance. Study the use and way of implementation of the Balanced Approach at the airport level and evaluate the extent to which the BA contributes to solving airport noise related problems at airports.

Group	Item	Description
WG2	O.02	Existing draft BA Guidance developed by FAA will be updated and improved with case studies.
WG2	O.03	Review and update the Airport Planning Manual, Part 2: Land Use and Environmental Control (Doc 9184) as required.
WG2	O.04	Estimate the environmental impact of curfews on destination countries with a case study for a major airport.
WG2	O.06.1	On emissions management systems: Deliver a report providing information on the use of EMS among airports, airlines, and air navigation providers in order to give a base of understanding in the aviation sector.
WG2	O.06.2	On emissions management systems: Based on the report in O.06 1) as appropriate, make recommendations on how CAEP could promote the use of EMS within the aviation system.
WG2	O.07.1	Examine the concept of environmental impact assessment applied to CNS/ATM and define the appropriate methodologies in order to quantify the benefits resulting from the implementation of CNS/ATM plans/ programmes and to identify appropriate ATM improvements.
WG2	O.07.2	Examine the concept of environmental impact assessment applied to CNS/ATM and define the appropriate methodologies in order to quantify the benefits resulting from the implementation of CNS/ATM plans/ programmes and to identify appropriate ATM improvements.
WG2	O.08	Based on the independent expert process, examine and make recommendations for noise, NOx and fuel burn with respect to air traffic operational goals in the mid term (10 years) and the long term (20 years).
WG2	O.09	Examine development of ICAO guidance on computing, assessing and reporting on aviation emissions at national and global levels.
WG2	O.10	Consider the development of environmental indicators in conjunction with other CAEP WGs.
WG2	O.11	Assess the effect of takeoff thrust and deeper cutback on noise and emissions, fuel consumption (constant weight) and climb-out time. This is an extension of the current task on Noise Abatement Departure Procedures (NADP) noise and emissions effects.
WG2	O.12	Assess and validate noise and emissions reductions accrued from the use of continuous descent arrival techniques (e.g. CDA). This item, considered as high priority item by TG3, would require definition of continuous descent techniques with other ICAO groups (OCP, OPSP) and is conditional on availability of assessment methods and supporting data.
WG2	O.13	Review of NAP R&D/implementation projects, including advanced noise abatement departure procedures. This item would provide an analysis of options including the evaluation of tradeoffs of environmental effects.
WG2	O.14	Assess benefits of steeper approach. This item should include review of present practice and review of implications for assessment methodologies. Operational and technological feasibility are also considered as part of the assessment.
WG2	O.15	Examine a case study on the management of "area-wide" aircraft noise. Study the noise arising from departing and arriving aircraft at locations 9 to 12 km away from the airport, and if appropriate further away, and investigate whether operational means rather than a change to the certification scheme would be the best way to address problems in these wider areas.
WG2	O.16	Develop and update the Airport Air Quality Guidance to include Dispersion Modelling, measurement and revision of the inventory chapter taking account of

Group	Item	Description
		emissions source characterisation and with external expertise as necessary on new aspects of the guidance material.
WG2	O.17	Continued coordination with FESG on ‘times-in-mode’ in relation to modelling capabilities.
WG2	O.18	Role of MBM in a management framework for local emissions. Prepare a report that describes the various technical, operational, mitigation and market-based measures available to address aircraft emissions impacting local air quality, identifies the factors that might inform a decision to choose a particular measure or measures, and notes the potential interrelationships between the measures.
WG2	O.19	Based on the information developed under O.18, develop draft text that could be used for the main page on the ICAO web site that describes the available measures and further directs the reader to the relevant ICAO guidance documents that have been adopted on the subject.
WG2	O.20	Coordinate with CAEP Secretary on future requests from GIACC to the group.
WG2	O.21	Improvements to ICAO carbon calculator.
WG2	O.22	Produce new guidance document replacing Circ. 303 with extended scope covering environmental impact assessment of CNS/ATM, methods for computing aviation emissions and environmental indicators and updating existing material, in particular on ATM. (related to items 7, 9, and 10)

Table 4. WG3 – Emissions Technical Issues

Group	Item	Description
WG3	E.01.1	Intergroup coordination: Coordinate with WG1 Rapporteurs on the WG1-WG3 Technology Interdependencies Group.
WG3	E.01.2	Intergroup coordination: Coordinate with WG1 Rapporteurs on programme schedules for development of both noise and emissions SARPs for future supersonic aeroplanes.
WG3	E.01.3	Intergroup coordination: Coordinate with other working group Rapporteurs as necessary, in particular on the new Goals Task [Item E.04].
WG3	E.01.4	Coordinate with WG2 and MODTF on formulation of metrics.
WG3	E.01.5	Coordinate with FESG on CAEP/6 NOx production cut-off and CAEP/8 NOx stringency and 2050 projections.
WG3	E.01.6	Intergroup coordination: Provide support to other UN Bodies as appropriate.
WG3	E.02	Research: Monitor & foster research to characterise further the air quality and global effects resulting from current and projected future aircraft exhaust emissions, including aviation’s contribution relative to other sources. Report on the results of this research, evaluating and highlighting the aviation environmental impacts relative to impacts from other sources.
WG3	E.03.1	Technology advances: a) Provide assessment of advances in aircraft and engine design technologies for subsonic and supersonic aircraft and the degree to which these technologies could influence gaseous emissions, smoke, particulate matter and fuel consumption;

Group	Item	Description
		including the potential benefits and trade-offs amongst various emissions and noise, the likely timescales for introduction and appropriate inputs for assessment of the associated economic costs and environmental benefits; and b) Working with WG2 and MODTF, formulate appropriate fuel efficiency metric(s) for use in assessment of CAEP Environmental goals (MODTF), air traffic operational goals (WG2) and aircraft and engine technology goals
WG3	E.03.2	Technology interdependencies: Provide the necessary inputs to MODTF to integrate technology responses and trade-offs into the CAEP benefit-cost modelling.
WG3	E.04.1.a	Technology goals: assessment of fuel burn technology advances to date with preliminary views on prospects for future fuel burn technologies.
WG3	E.04.1.b	Technology goals: conduct fuel burn technology Workshop with Independent Experts including provision of preliminary views on goals by IEs.
WG3	E.04.2	Technology goals: Monitor/review progress on medium and long term NOx technology goals.
WG3	E.04.3	Technology goals: Development of the Review process and structure in light of comments.
WG3	E.04.4	Technology goals: Develop, with other CAEP Groups, the means to use the output of the LTTG review process for: a) Identifying any gaps in relevant emissions data bases; b) Informing CAEP deliberations of possible timing and options for changes to the CAEP NO_x Standards; c) Providing modelling parameters to assess the probable range of future NO_x emissions; and d) Informing CAEP deliberations on the degree to which NOx technology improvements could influence progress towards achieving CAEP Environmental emission goals.
WG3	E.05.1	Particulate Matter: Recognising the interim approximate nature of the First Order Approximation (FOA) PM methodology: a) Evaluate and document sampling and measurement procedures for non-volatile particulate matter emissions, which, if appropriate, could be used in a certification methodology; b) Develop measurement and sampling techniques for volatile particulate emissions; and c) Assess and document scientific PM measurements as a means of validating and improving FOA PM methodology for environmental assessment purposes, with the ultimate objective of replacing FOA with PM measurement data, as confidence in measurement methods reaches an acceptable level.
WG3	E.05.2	Particulate Matter: Further characterise LTO particulate matter emissions from aircraft engines covering the state of the art science, FOA methodology, SAE-E31 progress, etc..

Group	Item	Description
WG3	E.05.3	Particulate Matter: Monitor the latest understanding of aviation PM impacts on both LAQ and climate change.
WG3	E.05.4	Particulate Matter: Assess the data required for environmental impact studies of aircraft particle emissions on the upper atmosphere and provide data (e.g. emissions factors), including uncertainties, for global emissions inventories of particles based upon ground-based and other measurement data.
WG3	E.05.5	Advise MODTF on future trends in LTO PM emissions resulting from technology advances.
WG3	E.06	Annex 16, Volume II: Maintain Annex 16, Volume II, taking account of updates to SAE-E31 documentation.
WG3	E.07	Environmental Technical Manual (ETM) developments: Further develop the emissions Environmental Technical Manual.
WG3	E.08.1	Methods & Standards. NO_x LTO stringency: a) Analyse the technological response to a range of NO_x stringency options up to CAEP6 minus 20% at OPR = 30 for application no sooner than 2012. b) Working with FESG, conduct appropriate analysis to assist decision making regarding a CAEP/6 Production cut-off provision
WG3	E.08.2	Methods & Standards. NO_x Cruise climb methodology: Monitor the need for and, subject to SG approval, the possible further development of the LTO NO_x vs. cruise climb NO_x relationship for future engine technologies to quantify control of mission emissions of NO_x.
WG3	E.08.3	Methods & Standards: Supersonic aircraft emissions: a) Promote new global impact assessments associated with a fleet of supersonic aircraft and report progress; and b) Review and revise, as appropriate, the existing methodology for supersonic aircraft engine emissions certification.
WG3	E.08.4	Methods & Standards: APU emissions: Explore improved characterisation of APU emissions through acquisition and reporting of data, including consideration of measurement and sampling issues and make appropriate recommendations.
WG3	E.09.1	Fuel composition - emissions effects: Review trends in aviation kerosene fuel supply composition.
WG3	E.09.2	Fuel composition - emissions effects: Promote improved understanding of the potential use and emission effects of alternative fuels.
WG3	E.09.3	Work with CRC, ASTM and other appropriate bodies to further evaluate the costs and benefits of a potential policy to remove sulphur from jet fuel.
WG3	E.10	Air Quality Guidance: Provide support to WG2, as appropriate, to assist the further development of the Local Air Quality Guidance.
WG3	E.11	Operational issues - emissions: Provide support to MODTF, as appropriate, to assist in development of models.
WG3	E.12	Engine Emissions Databank: Maintain and update Databank.
WG3	E.13	Coordinate with CAEP Secretary on future requests from GIACC to group.

Table 5. Market-based Measures Task Force (MBMTF)

Group	Item	Description
MBMTF	M.01	Update the Report on Voluntary Emissions Trading for Aviation.
MBMTF	M.02	Scoping study of issues related to linking open emission trading systems involving international aviation.
MBMTF	M.03	Conduct a scoping study into the application of emissions trading and offsets for local air quality in aviation.
MBMTF	M.04	Examine the potential for emissions offset measures as a further means of mitigating the effects of aviation emissions on global climate change.
MBMTF	M.05	In close cooperation with the ICAO Secretariat to keep CAEP informed of voluntary agreed measures to limit or reduce international aviation emissions, and to keep up-to-date guidelines that ICAO has developed for such measures, including a template voluntary agreement.
MBMTF	M.06	Coordinate with CAEP Secretary on future requests from GIACC to group.

Table 6. Modelling And Databases Task Force (MODTF)

Group	Item	Description
MODTF	MOD.01	Continue the candidate model evaluation process initiated in the previous work program, which calls for sensitivity tests, comparisons with "gold Standard data, and sample problems per MOD.02. Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis (e.g. stringency, CNS/ATM, market-based measures), and why there might be differences in modelling results.
MODTF	MOD.02	In support of the model evaluation process, conduct modelling sample problems (including technology response and cost-benefit analysis) to identify gaps in existing tools, to identify potential approaches to displaying interdependencies and to adapt models as necessary. (Note: Results not to be used for actual policy analysis.)
MODTF	MOD.03	To support CAEP environmental goals as stated in the current A35.5, conduct an updated trends assessment, for the baseline case (and forecasts), and various cases which consider technology and operational improvements. As directed by Steering Group, assess the contribution of CAEP policies toward achieving CAEP environmental goals.
MODTF	MOD.04.1	Examine how CAEP will directly compare the results of the various modelling tools, including the direct comparison of all aviation environmental impacts and costs versus benefits.
MODTF	MOD.04.2	This will draw on, as necessary, appropriate technical and scientific expertise from inside and outside CAEP, including a workshop.
MODTF	MOD.05	Provide support to CAEP Secretary on presentation of CAEP/7 environmental trends assessment.

Group	Item	Description
MODTF	MOD.06	Conduct policy option analyses as requested by CAEP. This effort requires coordinating work including a specific framework and set of assumptions required to support CAEP/8 analyses (WG1/2/3/FESG).
MODTF	MOD.07	Consider transition to a more comprehensive approach to assess proposed actions. This includes providing cost-benefit information and analyses in the form of sample information.
MODTF	MOD.08.1	2006 Airports Database
MODTF	MOD.08.2	2006 Movements Database
MODTF	MOD.08.3	2006 Fleet Database
MODTF	MOD.08.4	Population Database
MODTF	MOD.09	Develop a plan for coordinating MODTF activities including links and support required from WG1/2/3/FESG to conduct the CAEP/8 Work Programme.
MODTF	MOD.10	Define/assess environmental need for emissions reduction from technology.
MODTF	MOD.11	Examine and reconcile, if appropriate, the differences between the 2006 baseline data in the MODTF Common Operations Database (COD) and the baseline data in the FESG fleet forecast.
MODTF	MOD.12	Monitor Assembly Tasks K11, K12 and K22.
MODTF	MOD.13	Support NO_x production cut-off evaluation led by FESG.
MODTF	MOD.14	Coordinate with CAEP Secretary on future requests from GIACC to group.

Table 7. Items Deleted or Combined With Other Tasks in the Work Programme

Group	Item	Description
FESG	F.02 & F.04	Coordination with other groups and increased participation in FESG.
WG1/WG3	N.12.2/ E.03.2.b	Technology Interdependencies: "Evaluate" the Environmental Design Space Concept, the Technology Evaluator and other candidate systems as potential tools to aid assessment of technological responses and to identify technology tradeoffs.
WG1	N.20	Develop further guidance material in case of new certification of an existing aircraft making use of demonstration procedures not used in the original certification or aircraft modification applications.
WG2	O.05	Examine a case study on the management of "area-wide" aircraft noise

7.2 The tasks presented in Table 7 were removed from, or integrated into other tasks in the CAEP work programme at the CAEP Steering Group Meeting held in Seattle, Washington from 22 to 26 September 2008.

8. WORKING ARRANGEMENTS

8.1 The technical Committee met as a single body, with informal members only meetings convened as required. Discussions in the main meeting were conducted in Arabic, Chinese, English, French, Russian and Spanish. Some working papers were presented in English only. Papers were available electronically on the CAEP secure web site; no hard copies were provided to participants with the exception of the draft report for approval of the meeting. The report was issued in Arabic, Chinese, English, French, Russian and Spanish.

9. OPENING REMARKS BY THE FIRST VICE PRESIDENT OF THE ICAO COUNCIL

Good morning ladies and gentlemen. On behalf of the President, the Members of the Council, and the Secretary General of ICAO, it is a pleasure for me to welcome you to the Eighth Meeting of the Committee on Aviation Environmental Protection (CAEP).

My first thought is to point out how essential the work of CAEP is to ICAO in meeting its Strategic Objective on the environment – that of minimizing the adverse effects of global civil aviation on the environment and, in the process, moving ahead on three fundamental goals:

- limit or reduce the number of people affected by significant aircraft noise,
- limit or reduce the impact of aircraft engine emissions on local air quality, and
- limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

As you are all aware, we meet at an especially opportune time within the context of the global debate on the environment. Under ICAO, international aviation has produced the first globally-harmonized agreement, as a sector, on a goal to address CO_2 emissions resulting from its activities.

At the High-level Meeting on International Aviation and Climate Change, in October 2009, ICAO States endorsed a Programme of Action, reflecting the shared vision and strong will of our 190 member States. It includes deliberations on goals, measures and means to measure progress.

In November 2009, ICAO held a world conference and adopted a global framework on the development and deployment of sustainable alternative fuels for aviation, as an important means of reducing aviation emissions. Air transport is well positioned to become the first sector to use sustainable alternative fuels on a global basis.

These concrete actions and tangible global results show the remarkable progress of States and the air transport industry, towards achieving an efficient and sustainable global aviation under ICAO's leadership. The CAEP work was crucial to enable ICAO to reach such agreements and will be paramount as we move further in addressing this challenge.

Your track record is all to your credit. Over the years, CAEP has consistently provided the Organization with authoritative and credible technical information. Through your deliberations and recommendations, you and your predecessors have made it possible for ICAO to develop and promote realistic, comprehensive and forward-looking environmental solutions that have been endorsed by the world community. The depth and scope of your technical advice have proven essential in facilitating decisions of a political nature. That is what you do best, and that is what the Organization continues to expect from you.

During this latest CAEP/8 cycle, which culminates with the present meeting, you laid the foundation for decisions and actions in a number of critical areas.

I am pleased to see that substantial progress was achieved in the modelling and assessment area. This comes in response to a request from the last Assembly to continuously assess aviation's progress against environmental goals. As you know, reliable data is essential information for policy makers, if we want to establish sound and solid global policies to address the environmental impact of current and future aviation operations. From your analysis what we have learned is that, despite significant technological improvements over the years, the number of people exposed to significant aircraft noise and emissions affecting local air quality and climate change are expected to increase. Solutions must be found and CAEP has the responsibility to continue to project these trends and assess the policy options to address aviation environmental impacts using best available models and databases.

We will need all possible measures to address aviation impacts. It is important that CAEP continue to work on all fronts exploring the feasibility, potential environmental benefits and economic reasonableness of the options, and of course the interrelationships and trade-offs among these options as in your terms of reference.

On technology and operations, your work on the establishment of mid and long-term goals for technological improvements in noise, NO_x, and fuel-burn reduction is paramount to help guide us towards establishing realistic scenarios on what can be achieved so that we can better assess the need and extent of R&D and regulatory measures. We need globally-accepted methodologies to access the environmental benefits from operational measures. Without a harmonised approach, ICAO will not be able to properly quantify and report on the global benefits accrued from the various initiatives being taken internationally.

In the short term, we need to solidify the gains we have made to date by turning them into Standards and Recommended Practices. I look forward to your deliberations on the new NO_x Standard and on the work in Standard setting for CO_2 emissions as recommended by the High-level Meeting. At the same time, we must remind ourselves of the added pressure placed on aviation in terms of traffic growth by concerns both over aircraft noise and local air quality. It is essential that Standards be regularly developed and reviewed as new technologies and improvements appear.

As you can see, we have an aggressive agenda for this meeting and for the subsequent work. We also have to contend with constraints on resources for States and industry in the current economic environment. And yet, we know that committing the required resources will contribute to the sustainable development of aviation and the enormous benefits it generates for the world at large. In this sense, I would be most grateful if you could convey to your respective States and organizations our sincere appreciation for their cooperation and support. As our challenges in the environmental field grow, the priorities and the resources to undertake the challenges have to follow accordingly.

With this ongoing support, CAEP has been able to accomplish much over the past three decades or so. You have certainly gained the confidence and appreciation of the ICAO Council and of the aviation community. As we look ahead, however, there is another challenge we must address. As the pace of discussions on environmental issues accelerates, you must find ways to adapt your work and your deliberations to respond in a timely manner to these imperatives. This means revisiting working methods and timelines. There was a clear request from the Council to receive results from your work on a more frequent basis, maybe yearly. In this rapidly evolving environment, you will need to be flexible to provide timely responses to potentially unforeseen requests to address new topics of vital importance for the Organization.

As you know, the UNFCCC climate meeting in Copenhagen last December did not reach a legal agreement or a final decision on emissions from international aviation and maritime operations. ICAO's message to COP/15 was clear: the International Civil Aviation Organization is, and has always been, committed to addressing the impacts of international aviation on the global climate. That is what we will do in preparation for our next Assembly. I am sure that the Secretary of CAEP will convey to you the main outcomes and work required to respond to the outcomes of the High-level Meeting and the Alternative Fuels Conference.

Ladies and gentlemen, as we begin our deliberations, let us be guided by the conviction that what we will do in a few days may have a lasting impact for generations to come. I sincerely thank each and every one of you for your continuous support to the work of the Organization and for having given so much thought and energy in preparing this meeting. I wish you a very productive one.

— — — — — — — —

GENERAL

During this segment the meeting reviewed reports by the Secretariat on main developments and activities carried out during this CAEP cycle. Information was provided on membership, on the follow up of the Assembly requests, on the organization of meetings and events, and on cooperation with other UN bodies.

1. MEMBERSHIP AND PARTICIPATION IN CAEP ACTIVITIES

1.1 The Secretary presented the main developments since the CAEP/7 meeting, including changes in membership and membership rules. Three new members joined the Committee - China in 2007, Nigeria and Ukraine in 2009 - and one new observer – the Civil Air Navigation Services Organisation – CANSO in 2008.

1.2 At the sixteenth and seventeenth meetings of its 181st Session in June, the Council reviewed the participation of CAEP Members and Observers in CAEP activities. The Council approved a procedure whereby membership in the CAEP would be reviewed so that whenever a Member or Observer did not participate in three consecutive meetings of the CAEP or its Steering Group, it would automatically lose status as such, on the understanding that Members and Observers would be informed after they failed to attend two consecutive meetings. Accordingly, India lost its membership after failing to attend the three consecutive Steering Group meetings. The Council further accepted the principle that a CAEP Member could have an alternate.

1.3 During the 188th Session of the Council, it was decided that the Secretary General should review the CAEP membership rules. It was further decided that India would participate in CAEP/8 with temporary observer status pending further deliberation on this issue. Council will further consider this topic during its upcoming 189th Session in March 2010.

1.4 The level of attendance at CAEP meetings continued to vary greatly among CAEP members and observers during this CAEP cycle. The Secretariat conducted a comparative analysis of the participation between the CAEP/7 and CAEP/8 cycles and no significant improvements in participation took place despite the call from the 36th Session of the ICAO Assembly inviting States to continue their active support for ICAO‘s environment-related activities.

1.5 Participation in CAEP activities needs to be strengthened in order to guarantee the delivery of the work programme. There is clearly an imbalance in the contribution of States, with the majority of resources being provided by Australia, Brazil, Canada,, the United States, Japan, Switzerland and countries from the European Union, in particular the United Kingdom. Eight Member States have never sent an expert to any of the CAEP Working Group meetings (about 35 percent of the CAEP work force). The Secretary invited the Committee to provide suggestions on how best to address the issue of participation.

1.6 Discussion and conclusions

1.6.1 The Secretary pointed out that overall only 32% of the papers were received by the Secretariat by the deadline of Nov 30, 2009. Options to ensure that all members and observers have adequate time for review of the papers in preparation of the meeting need to be explored. The Chair emphasized the importance of timely submittal of papers and agreed that this topic be part of the discussions on working methods under the future work agenda item.

1.6.2 One member commended the Secretariat on migrating the CAEP websites to Sharepoint. She also highlighted the importance of streamlining access procedures so that more technical experts can benefit from the CAEP documentation. The Secretary highlighted that the access to websites follows the requests submitted by members. She pointed out that these websites are for the use of working groups' members only and therefore the access needs to be restricted accordingly.

2. LIAISON ACTIVITIES WITH OTHER UN BODIES

2.1 ICAO continued to cooperate closely with other United Nations (UN) bodies involved in the assessment of aviation's environmental effects and policy-making. Liaison carried on with the Intergovernmental Panel on Climate Change (IPCC), the United Nations Environment Programme (UNEP) Environmental Management Group (EMG), the International Maritime Organization (IMO), and the World Health Organization (WHO).

2.2 The Intergovernmental Panel on Climate Change (IPCC)

2.2.1 The IPCC has initiated preparation of the Fifth Assessment Report (AR5) and ICAO participated in its 31st Session that was commissioned with finalizing the scoping documents (chapter outlines) for the AR5, which is scheduled for completion in 2014. ICAO participated to ensure that aviation and climate change issues continue to be covered in the relevant chapters of the AR5. The request of WG3 on alternative fuel life cycle analysis was also brought to the attention of the IPCC.

2.2.2 ICAO particularly requested that the AR5:

a) further explore the effects of non-CO_2 aviation emissions;

b) updates the aviation traffic and GHG emissions trends;

c) includes the latest ICAO work on mitigation measures to address GHG emissions from international aviation;

d) covers interdependencies among aviation noise, air quality emissions and GHG emissions; and

e) addresses life-cycle analysis of the environmental benefits on the use of alternative fuels for aviation taking into account cross-sectoral issues.

2.2.3 The IPCC WGs chairs confirmed that the issues above would be covered. There might be a need for CAEP to follow up on these issues in support of the IPCC work, and this issue will be discussed under Future work.

2.3 IMO

2.3.1 Following the GIACC request, cooperation between ICAO and IMO has been strengthened during this CAEP cycle. In April 2009, the IMO's Secretary-General, the Executive

Secretary of the UNFCCC, and the President of the Council of ICAO, met in London to discuss COP15. Both Organizations also continued exchanging information on their respective Environmental Committees. The Secretariat presented information on CAEP and GIACC to IMO´s Maritime Environment Protection Committee 58^{th} and 59^{th} Sessions (MECP58 and MECP59) and IMO presented a paper to the HLM on MECP59 held in June 2009.

2.4 **UNEP EMG**

2.4.1 Cooperation continued on the development of the ICAO Carbon Calculator and on the Climate Neutrality project. The final meeting of the EMG agreed that ICAO, UNEP, and the IPCC will continue to work on the issue of accounting for the effects of greenhouse gas emissions other than C_{O2} from aviation. Further discussion on this matter will continue under Agenda item 2 when addressing the ICAO Carbon Calculator.

2.5 **WHO**

2.5.1 ICAO and CAEP WG1 cooperated with the WHO European Centre for Environment and Health in Bonn on noise issues. In October 2007, ICAO participated in the WHO’s technical meeting on aircraft noise to prepare a document titled “Evidence Review of Health Effects of Aircraft Noise”.

2.5.2 In October 2009 the WHO Regional Office for Europe published the Night noise guidelines for Europe. The new night noise limit proposed for European regions is an annual average night exposure not exceeding 40 decibels (dB). There are no specific guideline values for aircraft noise but several of the epidemiological studies used to derive the guidelines were conducted around airports and are based on aircraft noise. Also, for sleep disturbance and mobility, cause-effect relationships have been established for different noise sources and aircraft noise has been identified as causing the highest sleep disturbance. This publication was produced in support of the European Noise Directive and recommends countries to use them when introducing targeted noise limits. ICAO will continue to follow up WHO’s activities.

2.6 **Discussion and Conclusions**

2.6.1 A member congratulated the Secretariat in co-ordinating ICAO’s activities with other UN bodies. Adding to the items presented by the Secretariat, she noted that the IPCC is preparing a report on renewable energies. It will be important to ensure that CAEP is aware of this activity and coordinates with IPCC on any aviation related issues. It should be ensure that the future work programme of CAEP appropriately reflects the support required by liaison activities held in cooperation with other UN bodies, as required.

2.6.2 The same member also requested that the issue of climate change from aviation non-CO2 emissions (e.g. the request for support of CAEP to the UN) be further clarified during future work discussions. The meeting agreed to discuss the issue under the future work agenda item.

2.7 United Nations Framework Convention on Climate Change (UNFCCC)

2.7.1 The ICAO Assembly specifically requested ICAO to vigorously develop policy options to limit or reduce the environmental impact of aircraft engine emissions by developing concrete proposals and providing advice to UNFCCC encompassing technical solutions and market-based measures. Consequently, liaison with the Climate Secretariat has been one of the focus areas of the Secretariat since CAEP/7.

2.7.2 In December 2007, a comprehensive programme was launched at the 13th session of the Conference of Parties to the UNFCCC to enable the development of a future climate change agreement which would allow the effective and sustainable implementation of the Convention - the so called "Bali Road Map". In line with this programme, the Ad Hoc Working Group on Long-Term Cooperative Action (AWG LCA) was created, and the Working Group on Further Commitments for Annex I Parties under the Kyoto Protocol (AWG-KP) considered Annex I parties' commitments beyond the Protocol's first commitment period ending in 2012.

2.7.3 The AWG-LCA was required to complete its work by COP15 in December 2009, focusing on the key elements of the Bali Action Plan: shared vision for long-term cooperative action; mitigation efforts by both developed and developing countries; adaptation efforts; investment and finance needs; and development, deployment, dissemination and transfer of technology.

2.7.4 In line with the Bali roadmap, the UNFCCC has held 10 Climate Talks since Bali including four sessions of the Subsidiary Body for Scientific and Technological Advice (SBSTA) and two Conferences of the Parties to the UNFCCC (COP) and Conferences of the Parties serving as the meeting of the Parties to the Kyoto Protocol (COP/MOP) sessions.

2.7.5 The Secretariat participated in and/or sent written statements to all the UNFCCC sessions to update them with the ICAO's recent developments on international aviation and climate change. ICSO also held four side events (Accra, 2008, Bonn, June 2009; Barcelona, November 2009, Copenhagen, December 2009) The Steering Group meetings were updated on the development and the ICAO Statements and presentations can be found on the ICAO public website.

2.7.6 The issue of bunker fuels was historically covered by the SBSTA, where it had not progressed since 2005. In June 2008, SBSTA28, the SBSTA Chair conducted informal consultations and in the draft conclusions noted views by parties on work by the International Maritime Organization (IMO) and ICAO. It was agreed that for the next three sessions, the UNFCCC expected to receive information from both ICAO and IMO on bunker fuels, and Parties under the UNFCCC would exchange views based on this information, although no conclusions were expected. In May-June 2010 the issue of bunker fuels will again be considered by SBSTA to decide on any follow-up activities. Accordingly, reports on this topic were provided to SBSTA29 in June 2008, SBSTA30 in December 2008 and SBSTA31 in December 2009.

2.7.7 Taking into consideration the Bali Action Plan, AWG-LCA and AWG-KP considered how to address GHG emissions from international aviation and maritime transport (international bunker fuels) in a future agreement on climate change. Negotiations on AWG-LCA and AWG-KP covered different aspects including: the establishment of emissions reduction targets, guiding principles (e.g. principles of common but differentiated responsibilities and respective capabilities under the UNFCCC and the Kyoto Protocol), means for implementation (including financial issues), and the specific roles of ICAO and UNFCCC.

2.7.8 The Barcelona Climate Talks were held from 2 to 6 November 2009 and marked the final round of negotiations prior to COP15. AWG-LCA held the second part of its seventh session and AWG-KP resumed its ninth session. In the AWG-LCA 7 negotiations for emissions from international civil aviation resulted in seven different proposals for addressing international bunker fuels. The options include inter alia the possible roles for ICAO and the International Maritime Organization (IMO) in the establishment of emissions reduction targets and in the implementation of the aviation and maritime sectors' efforts to address their respective impacts on climate change. International aviation was also discussed in the AWG-LCA 7 Contact Group on Enhanced Action on the Provision of Financial Resources and Investment. Various options were proposed, including possible levies from international aviation transport. AWG-KP deliberations with relevance to aviation largely continue to focus on the establishment of emissions reduction targets beyond the first commitment period, ending in 2012.

2.8 Fifteenth Conference of the Parties to the UNFCCC (COP15)

2.8.1 COP15 took place in conjunction with the 5th meeting of COP/MOP (COP/MOP5) in Copenhagen, Denmark, from 7 to 19 December 2009. The conference also included the 31st session of the SBSTA (SBSTA31) as well as the 10th session of the AWG-KP (AWG-KP10) and the 8th session of the AWG-LCA (AWG-LCA8). From 16 to 18 December, 119 world leaders attended the Joint High-level Segment of COP15 and COP/MOP5.

2.8.2 Intense negotiations took place over the two weeks at the level of experts, Ministers and Heads of Governments. Questions concerning transparency and democratic process played out particularly during the second week of the conference. Differences emerged, *inter alia*, on whether work should be carried out in a smaller "friends of the Chair" group as well as on a proposal by the Danish Presidency to table new texts reflecting the work done by the AWG-KP and AWG-LCA. Most Parties urged that only texts developed in the AWG-KP and AWG-LCA by Parties should be the basis for further discussions.

2.8.3 During the Joint High-level Segment, informal negotiations took place in a group consisting of major economies and representatives of regional groups. Late on Friday evening, these talks resulted in political agreement entitled the "Copenhagen Accord". The Copenhagen Accord was then put forward to closing plenary of COP15 and COP/MOP5 on Saturday 19 December, but positions of Parties were divided. Some Parties agreed on the "adoption of Copenhagen Accord by COP15," while other Parties disagreed with the adoption due to the non-transparent process used to reach the Accord. As a compromise, COP15 took note of the Copenhagen Accord.

2.8.4 Excerpts from the Copenhagen Accord with relevance to aviation from are:

a) (paragraph 2) - "We agree that deep cuts in global emissions are required according to science, and as documented by the IPCC Fourth Assessment Report with a view to reduce global emissions so as to hold the increase in global temperature below 2 degrees Celsius, and take action to meet this objective consistent with science and on the basis of equity. We should cooperate in achieving the peaking of global and national emissions as soon as possible …"

b) (paragraph 8) - " … The collective commitment by developed countries is to provide new and additional resources, including forestry and investments through international institutions, approaching USD 30 billion for the period 2010 . 2012 with balanced allocation between adaptation and mitigation. Funding for adaptation will be prioritized for the most vulnerable developing countries, such as the least developed countries, small-island developing States and Africa. In the context of meaningful mitigation actions and transparency on implementation, developed countries commit to a goal of mobilizing jointly USD 100 billion dollars a year by 2020 to address the needs of developing countries. This funding will come from a wide variety of sources, public and private, bilateral and multilateral, including alternative sources of finance. New multilateral funding for adaptation will be delivered through effective and efficient fund arrangements, with a governance structure providing for equal representation of developed and developing countries. A significant portion of such funding should flow through the Copenhagen Green Climate Fund." ;

c) (paragraph 9) - "To this end, a High Level Panel will be established under the guidance of and accountable to the Conference of the Parties to study the contribution of the potential sources of revenue, including alternative sources of finance, towards meeting this goal."; and

d) (paragraph 12) - "We call for an assessment of the implementation of this Accord to be completed by 2015, including in light of the Convention's ultimate objective … ".

2.8.5 COP15 decided to extend the mandate of the AWG-LCA to enable it to continue its work, with a view to presenting the outcome of its work to COP16 for adoption. AWG-KP will also continue its work to deliver the results of its work for adoption by COP/MOP6. COP16 and COP/MOP6 will be hosted in Mexico from 29 November to 10 December in 2010.

International bunker fuels

2.8.6 Under the AWG-LCA8, informal groups for the elements of Bali Action Plan were established to facilitate their drafting work towards a "COP15 decision". The Informal group on bunker fuels met from 10 to 11 December. The majority of States expressed their support for global action on bunker fuels under ICAO and IMO, while some requested the inclusion of a clear text on Common But Differentiated Responsibilities (CBDR) and others requested including specific emissions reduction targets to these sectors.

2.8.7 On 14 December, the COP15 President announced that informal ministerial-level consultations would be held on bunker fuels assisted by Singapore and Norway. The informal ministerial-level consultation led by Singapore and Norway was held on 15 December to exchange views on bunker fuels, in particular on the issues of CBDR, targets and financing. There was recognition of the substantial efforts undertaken by ICAO and many parties expressed the view that ICAO and IMO should, in principle, address all the issues related to bunker fuels.

2.8.8 Due to the complexity of the overall process to move negotiations forward, no informal group on bunker fuels was convened from 16 December to the end of the Conference. Paragraph 32 of the draft report from AWG-LCA8 to COP15 remained as a place-holder for bunker fuels, without any conclusion on this issue. The specific implications to ICAO and CAEP will be addressed under Agenda Item 5.

3. OUTCOME OF GIACC AND HIGH-LEVEL MEETING

3.1 Group on International Aviation and Climate Change - GIACC

3.1.1 Following the request to the ICAO Council by the 36th Session of the ICAO Assembly in September 2007 to: "facilitate action by States by vigorously developing policy options to limit or reduce the environmental impact of aircraft engine emissions, developing concrete proposals and providing advice as soon as possible to the Conference of the Parties of the UNFCCC, encompassing technical solutions and market-based measures, while taking into account potential implications of such measures for developing as well as developed countries", the ICAO Council established the Group on International Aviation and Climate Change (GIACC) for the purpose of developing and recommending to the Council an aggressive Programme of Action on International Aviation and Climate Change. GIACC was supported technically by CAEP. CAEP working groups assisted GIACC by providing a fuel efficiency metric, global aviation CO_2 emissions projections, consideration of the development of a CO_2 Standard and providing a list of technical and market based measures.

3.1.2 The Assembly also requested the Council to convene at an appropriate time, taking into account the fifteenth meeting of the Conference of the Parties (COP15) of the United Nations Framework Convention on Climate Change (UNFCCC), a High-level Meeting to review the Programme of Action recommended by the Group. Accordingly, the High-level Meeting on International Aviation and Climate Change was convened at ICAO Headquarters from 7 to 9 October 2009.

3.1.3 The GIACC was established in January 2008, consisting of 15 senior government officials reflecting equitable participation from developed and developing States. The Group held its first meeting in February 2008 and its fourth and final meeting in May 2009. The result was a Programme of Action on International Aviation and Climate Change that was submitted to the Council for its consideration. The Council fully accepted the Programme of Action in June 2009 as a positive development to limit or reduce aviation's climate impact. Results of the Council's deliberations included an agreement on global fuel efficiency goals, the need to adopt a basket of measures to address aviation emissions, the establishment of a mechanism to collect traffic and fuel consumption data, and the concept of States' action plans.

3.1.4 The GIACC also identified areas for further work, including more ambitious medium and long-term goals, the development of a CO_2 Standard, a framework for market-based measures, and exploring approaches to provide technical assistance in the reporting process for developing States.

3.2 High-level Meeting on International Aviation and Climate Change (HLM)

3.2.1 The HLM fully accepted the GIACC's Programme of Action, as an important first step to address GHG emissions from international aviation, and reaffirmed ICAO's leading role in matters involving international civil aviation. It successfully approved a Declaration as well as Recommendations regarding further work by the ICAO Council on international aviation and climate change.

3.2.2 In summary, ICAO and its member States:

a) agreed on a global annual fuel efficiency improvement of 2% for the medium-term (up to 2020) and an aspirational global annual fuel efficiency improvement of 2% for the long-term (up to 2050);

b) recognized that these goals are unlikely to deliver the level of reduction necessary to stabilize and subsequently reduce aviation's absolute emissions contribution to climate change, and that more ambitious goals will need to be considered to deliver a sustainable path for aviation;

c) declared that ICAO and its member States, along with relevant organizations will keep working together to undertake further work on medium and long-term goals, including exploring the feasibility of more ambitious goals, including carbon-neutral growth and emissions reductions, for consideration by the 37th Session of the ICAO Assembly;

d) agreed on the development of a global CO_2 Standard for new aircraft types consistent with CAEP recommendations;

e) strongly encouraged wider discussions on the development of alternative fuel technologies and the promotion of the use of sustainable alternative fuels in aviation;

f) agreed to facilitate the implementation of operational changes and the improvement of air traffic management and airport systems aiming to reduce emissions from international aviation;

g) agreed that ICAO will establish a process to expeditiously develop a framework for market-based measures in international aviation;

h) agreed to further elaborate on measures to assist developing States as well as facilitate access to financial resources, technology transfer and capacity building;

i) in order to monitor progress towards reaching the goals, States are encouraged to submit their action plans, outlining their respective policies and actions, and annual reporting on international aviation CO_2 emissions to ICAO; and

j) agreed that ICAO will regularly report CO_2 emissions from international aviation to the UNFCCC, as part of its contribution to assessing progress made in the implementation actions in the sector.

3.2.3 In November 2009, the ICAO Council fully accepted the outcome of the High-level Meeting, including its Declaration and Recommendations, and decided on further action for consideration by the 37th Session of the ICAO Assembly in September 2010 and beyond. The HLM meeting also resulted in concrete requests for action by CAEP. These requests will be addressed under Agenda Item 5.

3.3 Discussion and Conclusions

3.3.1 A member congratulated ICAO on its success in showcasing aviation sector's achievements on the UN platforms including the UNFCCC. It was further pointed out that the UNFCCC and ICAO definitions of "international" are different and this very important distinction should be borne in mind in discussions on reporting international aviation's data on GHG emissions or else data would not be as useful to UNFCCC.

3.3.2 The meeting agreed to further consider the implications to CAEP work during the future work agenda item.

4. ICAO FUEL DATA COLLECTION MEETING

4.1 In response to the GIACC's request to explore ways of enhancing the collection of data necessary to measure emissions performance, while taking into account existing guidance, the Secretariat organized a one-day meeting on 23 March 2009. The meeting brought together more than 20 experts in international policy, inventory preparation, sources of available data, and verification and explored the sources of data available to support the environmental analysis of aviation and the main points to be considered to enhance future data collection activities related to the assessment of aviation CO_2 emissions in ICAO. The results of this meeting and further action by the Committee will be addressed under Agenda Item 2.

5. WAAF/2009 AND CAAF/2009

5.1 The 36th Session of the ICAO Assembly also requested the Council to "promote improved understanding of the potential use, and the related emissions impacts, of alternative aviation fuels". As a result, ICAO held two major events related to the use of alternative fuels by aviation during 2009. A workshop was held in February as a preparatory event for the conference in November.

5.2 The Conference on Aviation and Alternative Fuels (CAAF/2009) was held in Rio de Janeiro, sponsored by Brazil, as an important step to promote improved understanding of the potential use and emission effects of sustainable alternative fuels and to facilitate their development and deployment. The Conference endorsed the use of sustainable alternative fuels for aviation, particularly the use of drop-in fuels in the short to medium-term, as an important means of reducing aviation emissions.

5.3 CAAF/2009 adopted a Declaration and Recommendations affirming the commitment of States and industry to develop, deploy and use sustainable alternative fuels to reduce aviation's emissions. In order to facilitate, on a global basis, the promotion and harmonization of initiatives that encourage and support the development of sustainable alternative fuels for aviation, the Conference established an ICAO Global Framework for Aviation Alternative Fuels. The Global Framework will be a living document that will be made available on the ICAO website and updated whenever new information is provided by Member States and International Organizations.

5.4 CAAF/2009 also called for ICAO's support in the environmental aspects of alternative fuels for aviation. Specifically, it is anticipated that CAEP could support activities related to a lifecycle analysis framework, sustainability requirements, and local air quality. This topic will be discussed in detail under Future Work.

5.5 Discussion and Conclusions

5.5.1 A member congratulated ICAO on holding CAAF/2009 and on its successful outcome. It was stated that ICAO and CAEP should coordinate work on sustainability requirements and life-cycle analysis with other relevant fora. Other members and observers supported this point and agreed that this accords well with the CAAF/09 recommendations where it was stressed that the duplication of effort should be avoided. The Chair emphasized the importance of keeping informed of progress in relevant bodies and organizations so that any new work builds upon what has already been accomplished. Also, regarding trade-offs related to LAQ and climate change, any support from CAEP should be addressed under future work.

5.5.2 The meeting agreed to further consider the requests of CAAF during the future work agenda item.

— — — — — — — —

Agenda Item 1: Review of the assessments of the present and future impact of aircraft noise and engine emissions

1.1 REPORT OF THE FESG

1.1.1 The Co-Rapporteurs of the Forecast and Economic Analysis Support Group (FESG) presented the group's report. The work programme of the FESG for CAEP/8 was originally established at CAEP/7 and was subsequently amended during the cycle to reflect guidance provided by the Steering Group.

1.1.2 Traffic and fleet forecasts (Task F.01.1)

1.1.2.1 In February 2007, FESG was tasked to produce a new traffic and fleet forecast over a 30-year time horizon in support of the economic analysis of the NO_x stringency options under consideration for CAEP/8 and the assessment of the environmental goals.

1.1.2.2 The FESG CAEP/8 forecast was developed for both passenger and freight services and included the following elements:

a) Passenger traffic forecast;

b) Passenger fleet forecast;

c) Forecast of aircraft with less than 20 seats; and

d) Freighter traffic and fleet forecast.

1.1.2.3 The FESG consensus-based passenger traffic forecast is an unconstrained (not capacity restricted) forecast that was developed for a 20-year time horizon (from 2006 to 2026). A 10-year estimate was then added to the 20-year base forecast to extend the forecast time horizon to year 2036 (to cover an overall time horizon of 30 years).

1.1.2.4 Previous FESG forecasts that were prepared for CAEP/4, CAEP/5, and CAEP/6 were developed solely for the scheduled operations of commercial civil aviation aircraft, defined as aircraft operated by airlines. In response to a request made by the MODTF to take into account non-scheduled operations as well, FESG included charter flights in the development of the CAEP/8 forecast. However, other non-scheduled operations (such as general aviation and military operations) were not included.

1.1.2.5 In addition, past FESG forecasts did not include aircraft with less than 20 seats. As a number of engines considered in the analysis of the NO_x stringency options for CAEP/8 are fitted to these aircraft, at the Steering Group meeting held in November 2007, FESG was asked to reflect this category of aircraft in its analysis. The MODTF indicated that a forecast was needed for these aircraft in order for the environmental goals to be developed.

1.1.2.6 The total international and domestic passenger traffic forecasts are presented in Table 1, expressed in terms of average annual growth rate, and in Table 2, in revenue passenger-kilometres. In the most likely scenario (central forecast), the world passenger traffic, expressed in revenue passenger-kilometres, is expected to grow at the average annual growth rate of 4.9 per cent over the forecast period and at 4.4 per cent over the extension period. These growth rates fall to 4.2 per cent and 3.6 per cent respectively under the low scenario (pessimistic) and increase to 5.4 and 4.8 per cent respectively under the high scenario (optimistic).

1.1.2.7 Tables 3, 4 and 5 illustrate the detailed forecast by major route group for the most likely (central forecast), high (optimistic) and low (pessimistic) scenarios, respectively.

Table 1. CAEP/8 Passenger Traffic Growth Rate Forecast (Average annual growth rate of revenue passenger-kilometres) – Central Forecast and Sensitivity Analysis

Most likely, High and Low Scenarios

Scenario / Sector	**2006 -2016**	**2016 -2026**	**2026 -2036**	**2006 -2026**	**2006 -2036**
High Scenario (Optimistic)	[% growth]				
Total International	5.9	5.5	5.0	5.7	5.5
Total Domestic	5.0	4.7	4.4	4.9	4.7
Global [International + Domestic]	**5.5**	**5.2**	**4.8**	**5.4**	**5.2**
Most Likely Scenario (Central Forecast)					
Total International	5.4	5.0	4.6	5.2	5.0
Total Domestic	4.5	4.3	4.1	4.4	4.3
Global [International + Domestic]	**5.1**	**4.8**	**4.4**	**4.9**	**4.8**
Low Scenario (Pessimistic)					
Total International	4.8	4.4	4.0	4.6	4.4
Total Domestic	3.6	3.2	2.8	3.4	3.2
Global [International + Domestic]	**4.3**	**4.0**	**3.6**	**4.2**	**4.0**

Table 2. CAEP/8 Passenger Traffic Forecast – Central Forecast and Sensitivity Analysis

Most likely, High and Low Scenarios

	Revenue passenger-kilometres [RPKs]			
	Actual	**CAEP/8 Forecast**		
Scenario / Sector	**2006**	**2016**	**2026**	**2036**
High Scenario (Optimistic)	[billions]			
Total International	2 682.6	4 744.9	8 075.8	13 216.7
Total Domestic	1 588.4	2 585.0	4 098.8	6 314.1
Global [International + Domestic]	**4 271.0**	**7 329.8**	**12 174.6**	**19 530.8**
Most Likely Scenario (Central Forecast)				
Total International	2 682.6	4 551.3	7 416.1	11 592.6
Total Domestic	1 588.4	2 474.3	3 782.5	5 657.2
Global [International + Domestic]	**4 271.0**	**7 025.6**	**11 198.6**	**17 249.8**
Low Scenario (Pessimistic)				
Total International	2 682.6	4 276.8	6 559.6	9 672.6
Total Domestic	1 588.4	2 257.2	3 091.3	4 074.3
Global [International + Domestic]	**4 271.0**	**6 533.9**	**9 650.9**	**13 747.0**

[1] Average annual growth rate of revenue passenger-kilometres.

Table 3. CAEP/8 Passenger Traffic Growth Rate Forecast (Average annual growth rate of revenue passenger-kilometres)– Most likely scenario (Central forecast)

Sector / Route Groups	2006 -2016	2016 -2026	2026 -2036	2006 -2026	2006 -2036
International			[% growth]		
1. North Atlantic	4.8	4.3	3.8	4.5	4.2
2. South Atlantic	5.8	5.6	5.3	5.7	5.6
3. Mid Atlantic	5.8	5.3	4.8	5.5	5.2
4. Transpacific	6.4	5.6	4.9	6.0	5.6
5. Europe ←→ Asia/Pacific	5.8	5.3	4.8	5.5	5.2
6. Europe ←→ Africa	5.5	5.5	5.5	5.5	5.5
7. Europe ←→ Middle East	6.4	5.6	4.9	6.0	5.6
8. North America ←→ South America	5.4	4.6	3.9	5.0	4.6
9. North America ←→ Central America and Caribbean	4.7	4.7	4.7	4.7	4.7
10. Middle East ←→ Asia / Pacific	6.5	5.7	5.0	6.1	5.7
11. Intra Africa	6.0	6.0	6.0	6.0	6.0
12. Intra Asia/Pacific	6.3	5.8	5.3	6.0	5.7
13. Intra Europe	4.3	3.8	3.3	4.0	3.7
14. Intra Latin America	6.0	6.0	6.0	6.0	6.0
15. Intra Middle East	5.8	5.3	4.8	5.5	5.2
16. Intra North America	3.8	3.3	2.8	3.5	3.2
17. Other International Routes	5.2	5.2	5.2	5.2	5.2
Total International	**5.4**	**5.0**	**4.6**	**5.2**	**5.0**
Domestic					
18. Africa	5.8	5.6	5.3	5.7	5.6
19. Asia/Pacific	7.4	6.6	5.9	7.0	6.6
20. Europe	3.8	3.3	2.8	3.5	3.2
21. Latin America	6.1	5.9	5.6	6.0	5.9
22. Middle East	4.6	4.4	4.1	4.5	4.4
23. North America	3.0	2.5	2.0	2.7	2.4
Total Domestic	**4.5**	**4.3**	**4.1**	**4.4**	**4.3**
Global [International + Domestic]	**5.1**	**4.8**	**4.4**	**4.9**	**4.8**

Table 4. CAEP/8 Passenger Traffic Growth Rate Forecast (Average annual growth rate of revenue passenger-kilometres) – High Scenario (Optimistic)

Sector / Route Groups	2006 -2016	2016 -2026	2026 -2036	2006 -2026	2006 -2036
International			[% growth]		
1. North Atlantic	5.0	4.5	4.0	4.7	4.5
2. South Atlantic	6.5	6.3	6.0	6.4	6.3
3. Mid Atlantic	5.9	5.4	4.9	5.6	5.3
4. Transpacific	6.5	5.7	5.0	6.1	5.7
5. Europe ←→ Asia/Pacific	6.5	6.0	5.5	6.3	6.0
6. Europe ←→ Africa	6.3	6.3	6.3	6.3	6.3
7. Europe ←→ Middle East	8.1	7.3	6.6	7.7	7.3
8. North America ←→ South America	5.6	4.9	4.2	5.3	4.9
9. North America ←→ Central America and Caribbean	5.0	5.0	5.0	5.0	5.0
10. Middle East ←→ Asia / Pacific	7.0	6.2	5.5	6.6	6.2
11. Intra Africa	6.9	6.9	6.9	6.9	6.9
12. Intra Asia/Pacific	6.4	6.0	5.5	6.2	5.9
13. Intra Europe	4.7	4.2	3.7	4.4	4.2
14. Intra Latin America	6.4	6.4	6.4	6.4	6.4
15. Intra Middle East	7.4	6.9	6.4	7.2	6.9
16. Intra North America	4.8	4.3	3.8	4.5	4.3
17. Other International Routes	5.2	5.2	5.2	5.2	5.2
Total International	**5.9**	**5.5**	**5.0**	**5.7**	**5.5**
Domestic					
18. Africa	5.9	5.7	5.4	5.8	5.7
19. Asia/Pacific	7.5	6.7	6.0	7.1	6.7
20. Europe	4.5	4.0	3.5	4.3	4.0
21. Latin America	6.7	6.5	6.2	6.6	6.5
22. Middle East	5.6	5.4	5.1	5.5	5.4
23. North America	3.6	3.1	2.6	3.3	3.1
Total Domestic	**5.0**	**4.7**	**4.4**	**4.9**	**4.7**
Global [International + Domestic]	**5.5**	**5.2**	**4.8**	**5.4**	**5.2**

Table 5. CAEP/8 Passenger Traffic Growth Rate Forecast(Average annual growth rate of revenue passenger-kilometres) – Low Scenario (Pessimistic)

Sector / Route Groups	2006 -2016	2016 -2026	2026 -2036	2006 -2026	2006 -2036
International			[% growth]		
1. North Atlantic	4.0	3.5	3.0	3.7	3.5
2. South Atlantic	4.4	4.2	3.9	4.3	4.2
3. Mid Atlantic	4.9	4.4	3.9	4.7	4.4
4. Transpacific	5.8	5.1	4.3	5.5	5.1
5. Europe ←→ Asia/Pacific	5.7	5.1	4.7	5.4	5.2
6. Europe ←→ Africa	4.9	4.9	4.9	4.9	4.9
7. Europe ←→ Middle East	5.0	4.2	3.5	4.6	4.2
8. North America ←→ South America	5.3	4.5	3.8	4.9	4.6
9. North America ←→ Central America and Caribbean	4.0	4.0	4.0	4.0	4.0
10. Middle East ←→ Asia / Pacific	6.2	5.4	4.7	5.8	5.4
11. Intra Africa	5.5	5.5	5.5	5.5	5.5
12. Intra Asia/Pacific	5.6	5.1	4.6	5.3	5.0
13. Intra Europe	3.3	2.8	2.3	3.1	2.8
14. Intra Latin America	5.1	5.1	5.1	5.1	5.1
15. Intra Middle East	4.5	4.0	3.5	4.2	3.9
16. Intra North America	3.2	2.7	2.2	3.0	2.7
17. Other International Routes	4.6	4.6	4.6	4.6	4.6
Total International	**4.8**	**4.4**	**4.0**	**4.6**	**4.4**
Domestic					
18. Africa	5.5	5.3	5.0	5.4	5.3
19. Asia/Pacific	5.5	4.7	4.0	5.1	4.7
20. Europe	2.7	2.2	1.7	2.5	2.2
21. Latin America	5.1	4.9	4.6	5.0	4.9
22. Middle East	4.2	3.9	3.7	4.0	3.9
23. North America	2.6	2.1	1.6	2.3	2.1
Total Domestic	**3.6**	**3.2**	**2.8**	**3.4**	**3.2**
Global [International + Domestic]	**4.3**	**4.0**	**3.6**	**4.2**	**4.0**

1.1.2.8 The passenger fleet mix forecast by seat category is presented in Table 6 for the most likely scenario. The fleet of passenger aircraft is expected to grow by an average annual rate in the range of 3.0 to 3.2 per cent between 2006 and 2036. As a result, the size of the fleet will almost double by 2026 and the size of the 2036 fleet is expected to be more than 2.5 times that of 2006.

Table 6. CAEP/8 Passenger Fleet Mix Forecast by Seat Category
Most Likely Scenario (Central Forecast)

Seat category	2006	2016	2026	2036
20-50	4 053	2 975	3 042	3 643
51-100	1 813	4 152	5 697	7 650
101-150	5 896	7 542	9 309	11 445
151-210	3 984	6 294	8 593	11 375
211-300	2 003	3 040	4 446	6 499
301-400	824	1 314	2 048	3 261
401-500	159	405	950	1 723
501-600	41	120	307	938
601-650		65	394	969
Total	**18 773**	**25 907**	**34 786**	**47 503**

1.1.2.9 Although the fastest growth is expected to be observed in the fleet of aircraft with more than 400 seats, their share in the total fleet (in terms of number of aircraft) will be about 5 and 7.5 per cent in 2026 and 2036 respectively. The lowest growth is expected to be in the 101-150 seat category that will still represent 27 and 24 per cent of the total in 2026 and 2036, respectively. The fleet of aircraft in the 51-100 seat category is expected to grow at an average annual rate of approximately 5 per cent up to 2036, causing the 20-50 seat-category to shrink slightly from its 2006 size.

1.1.2.10 In Table 6, there is an abrupt decline in the number of aircraft in the 20-50 seat category from 2006 to 2016, from 4,053 to 2,975 aircraft. This can be explained by the following two factors:

a) the use of aircraft in the 20-50 seat category by air carriers is limited. As traffic grows, air carriers switch to bigger aircraft as reflected in the fast growth of the 51-100 seat category; and

b) the existing fleet remained in passenger service for a longer period of time than usual, due to the non-availability of replacement aircraft.

1.1.2.11 The fleet forecast for business jet aircraft is presented in Table 7.

Table 7. CAEP/8 Forecast of aircraft with less than 20 seats
Forecast of Business Jet Aircraft - **Fleet in service**

Regions	2006	2016	2026	2036
Africa	248	429	807	1 445
Asia/Pacific	390	980	2 711	5 334
Europe	1 736	3 631	7 100	11 566
Middle East	221	296	556	906
Latin America and Caribbean	1 178	2 190	4 117	6 706
North America	10 273	12 872	17 642	23 709
Total	**14 046**	**20 398**	**32 933**	**49 666**

1.1.2.12 In contrast to the passenger forecast (developed by route groups), the freighter forecast has been developed for 6 regions. The forecast, expressed in revenue tonne-kilometres, is presented in Table 8.

Table 8. CAEP/8 Freighter Traffic Forecast by Region of domiciliation[1]
Most Likely Scenario (Central Forecast)

	Revenue Tonne-Kilometres [millions]			
Regions	**2006**	**2016**	**2026**	**2036**
Africa	3 321	6 107	10 823	19 657
Europe	46 833	75 681	120 115	204 542
Middle East	9 834	21 791	38 769	69 597
Latin America	5 035	9 258	16 408	29 008
North America	61 315	105 298	176 068	305 167
Asia	58 553	121 865	240 378	434 586
Total	**184 890**	**340 000**	**602 560**	**1 062 557**

[1] Cargo carried in passenger services lower-hold and freighter services main deck.

1.1.2.13 Tables 9 and 10 present the freighter fleet forecast for the most likely scenario by seat category and by region of domicile, respectively.

Table 9. CAEP/8 Freighter Fleet Mix Forecast by Seat Category
Most Likely Scenario (Central Forecast)

Seat category	2006	2016	2026	2036
<50	1 007	1 035	1 176	1 333
50-100	383	445	558	793
101-150	251	425	630	827
151-210	481	640	905	1 264
211-300	925	1 107	1 321	1 596
301-400	197	371	554	839
401-500	159	320	509	786
501-600	-	25	68	184
Total	**3 403**	**4 368**	**5 721**	**7 622**

Table 10. CAEP/8 Freighter Fleet Mix Forecast by Region of Domiciliation
Most Likely Scenario (Central Forecast)

Region	2006	2016	2026	2036
Africa	295	403	572	886
Asia	331	602	963	1 574
Europe	1 024	1 137	1 404	1 721
Latin America	146	221	332	514
Middle East	82	188	311	444
North America	1 526	1 817	2 139	2,483
Total	**3 403**	**4 368**	**5 721**	**7 622**

1.1.3 **Projections to 2050 (Task F.01.2)**

1.1.3.1 The FESG prepared traffic projections to 2050 with the objectives of allowing CAEP to:

a) assess environmental goals;

b) assess Long Term Technology Goals (LTTG); and

c) provide inputs to external parties.

1.1.3.2 The projections of traffic demand until 2050 are shown in Figure 1. The range of traffic demand projections up to 2050 demonstrates the extent to which long term demand is influenced by a range of factors on which each scenario is based. Each of the specific assumptions within each scenario is subject to uncertainty (e.g. the degree of technological development) because of the inability to anticipate what the world will look like that far into the future. The following factors are among those likely to strongly influence the demand for air traffic:

a) Population and economic growth;

b) Energy availability and price;

c) Technology development;

d) Regulations and government policies;

e) Airport capacity development;

f) Attitudes towards travel and the environment;

g) Airline operating costs; and

h) Political pressures.

1.1.3.3 The scenarios have been used to show how traffic demand may change under different possible circumstances. It is therefore important to understand the underlying assumptions and storylines of each scenario discussed because it is those assumptions that drive the resulting air traffic demand. The scenarios used to develop these forecasts were obtained from four primary sources: CONSAVE 2050, Manchester Metropolitan University work using the IPCC Special Report on Emission Scenarios (SRES), IPCC92 and IPCC99 scenarios, and projection of the FESG FTG CAEP/8 forecast.

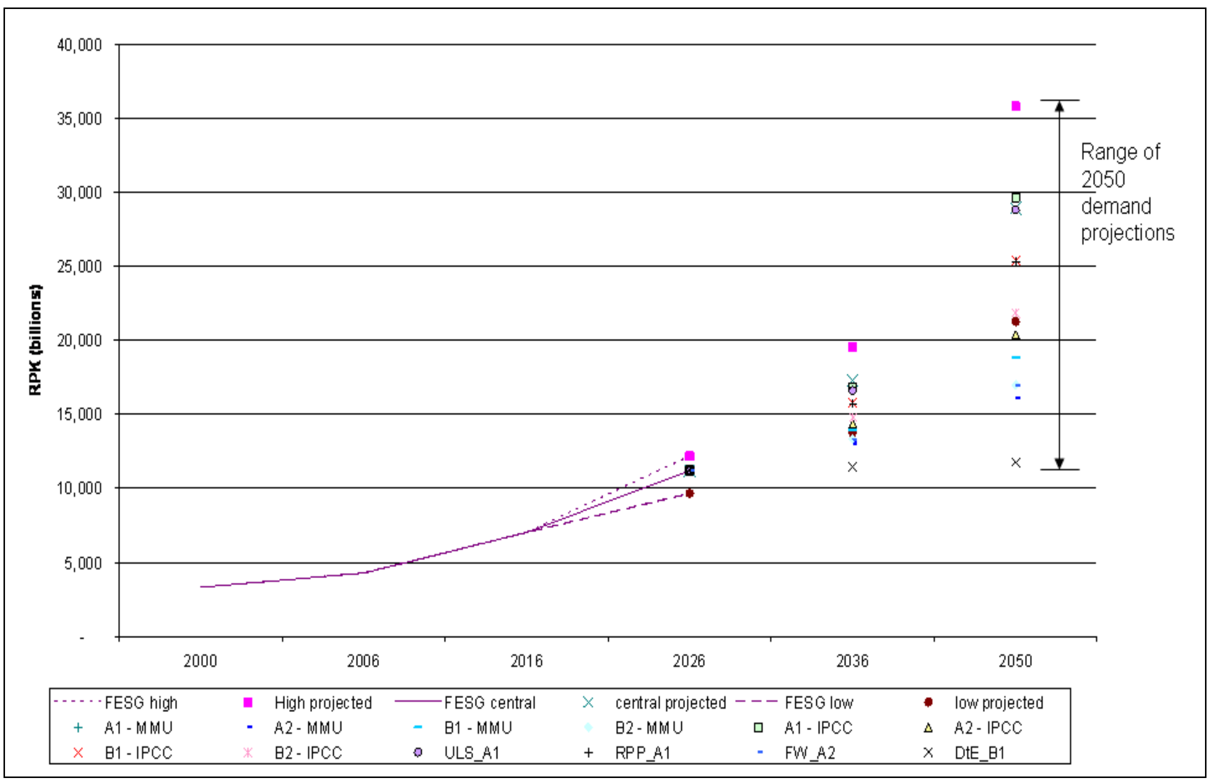


Figure 1: Projections of traffic demand to 2050

CONSAVE 2050

1.1.3.4 CONSAVE 2050 was commissioned by the European Commission to provide constrained scenarios on aviation demand and emissions, addressing key aspects of interest to stakeholders such as the aviation industry, policymakers, climatologists and transport researchers. The CONSAVE background scenarios, developed by Institute for Applied System Analysis (IIASA), elaborate on the above-mentioned IPCC SRES scenarios. On this basis, four air transport scenario storylines were developed by DLR and quantified with the AERO-MS model . The four scenarios are:

1) “Unlimited Skies”: market forces are assumed to address externalities by incentivising vigorous technological innovation. This helps to overcome potential barriers arising from the formidably high growth in air transport of this scenario;

2) “Regulatory Push & Pull”: strict governmental regulation provides for a “pulling-in” of desirable technologies and characteristics via regulation and incentives, and a “pushing-out” of undesirable ones. This is a high-growth scenario;

3) “Fractured World”: due to political, religious and social divergences, the world is divided into blocks with high tensions, occasional confrontations, terrorism, causing high security and standardisation problems/costs. This leads to low growth in inter-regional flights; and

4) “Down to Earth”: the problem to achieve sustainability is addressed by uncompromising changes in lifestyles. Air transport, especially long distance trips, are regarded very critically for the mainstream, and the resulting demand is low.

MMU work using the IPCC Special Report on Emission Scenarios (SRES)

1.1.3.5 IPCC SRES (2000) were designed to cover a broader range of topics than the previous (IS92) scenarios. These scenarios provide input for evaluating climatic and environmental consequences of future emissions, and for assessing alternative mitigation and adaptation strategies. Forty scenarios have been developed (though not all are relevant to the Projection Task Group’s (PTG) work), covering the current range of uncertainties in emissions modelling. Grouped into four “families” (A1, A2, B1 and B2), the scenarios examine trends in technological change and economic developments such as increase/decrease in the income gap between developed and developing countries.

IPCC 92 and 99 scenarios (The IPCC Special Report, 1999) – updated

1.1.3.6 These were emissions scenarios primarily designed for driving global circulation models and to develop global climate change scenarios. ‘IS92’ scenarios were the first global scenarios to provide estimates for the full range of climate change emissions. They were adopted for use to provide the 50-year trends for the IPCC report on Aviation and the Global Atmosphere (1999). The IPCC report contains a total of six scenarios – the ICAO/CAEP FESG scenarios – developed by FESG by combining the IPCC 1992 scenarios - the IS92a, c and e scenarios - with two technology scenarios of International Coordinating Council of Aerospace Industries Associations (ICCAIA).

Projection of the FESG FTG CAEP/8 forecast

1.1.3.7 The Forecast Task Group produced a consensus-based traffic forecast to 2026. They then extended this forecast forward to 2036 using an approach based on expert judgement and reflecting regional differences in market maturity (again based on judgement). This forecast extension has been rolled forward by PTG on the assumption that the rates of growth continue to decline over time.

1.1.4 **Review of the Economic Models (Task F.03)**

1.1.4.1 The FESG conducted a review of the Aviation Environmental Portfolio Management Tool Partial Equilibrium Block (APMT-PEB) and the FESG NO_x Cost Spreadsheet Model to assess their appropriateness for supporting the economic analysis of NO_x stringency options. Both tools were used in the FESG and MODTF NO_x Stringency Sample problem analysis that is described in paragraph 1.2.10. The FESG determined that both of the tools are appropriate for use in assessing the cost effectiveness of NO_x stringency options.

1.1.5 **Market-based Measures (Task F.05)**

1.1.5.1 The Market-based Measures Task Group was created within FESG to conduct an economic analysis of the financial impact of including international aviation in existing trading schemes and to undertake a literature review of cost-benefit analysis of existing trading systems with a special emphasis on how it has been applied to other sectors in order draw some pertinent lessons learned for the aviation sector. These tasks were completed and the reports submitted by FESG to the Steering Group as the final deliverables relative to these tasks. The Report was approved by the CAEP Steering Group in June 2009.

1.1.5.2 The group found that there are a broad range of views, supported by a different degree of evidence, on each of the key themes of competition, cost pass through, windfall profits, auctioning, benchmarking, developing countries, and the effect on the market price of carbon.

Cost Pass Through

1.1.5.3 The impacts on competition and cost pass through were found to be highly dependent on the nature of the ETS introduced. The studies addressed three different situations:

1) coverage of the ETS is only partial, leaving airlines from some countries with no emission reduction obligations. In this case the airlines not covered by the system (e.g., those from developing countries) gain an advantage on routes in common markets;

2) all airlines are subject to the same ETS conditions. In this case there is no competitive distortion and airlines can (and probably will) pass their costs on to consumers; and

3) the ETS is regional, hence the impact on individual airlines may vary.

1.1.5.4 Regarding the third case, the studies differed in their views of cost pass through; some are based on economic theory and others have tried to consider specific characteristics of the airline industry.

Cost pass through levels are likely to differ according to the particular markets being considered and the timeframe of analysis, i.e. long term effects or short term.

Windfall Profits

1.1.5.5 The studies also varied widely in their conclusions on windfall profits. This is related to the issue of cost pass through, on which there are differing views.

Auctioning

1.1.5.6 Auctioning was an important issue in terms of compliance costs because with a higher level of auctioning, fewer allowances would be allocated for free. Where auctioning levels are higher, a greater impact on airlines' costs would be expected and hence, there would be potentially greater impacts on demand, though revenues would be generated that could be used to further the benefits of the scheme if directed to that purpose. Auctioning was found to have no further reducing effect on CO_2-emissions beyond those that are set by an emissions cap; however, there might be some effects on other aviation emissions like NO_x, due to the reduction in demand induced by the extra costs.

Benchmarking

1.1.5.7 Benchmarking as a way to allocate emissions allowances for free may have implications for airline activity and would be likely to affect airlines differently depending on their levels of activity, efficiency and costs of purchasing allowances. There was no conclusive finding on the effect on the price of allowances resulting from the addition of the aviation sector to an existing ETS.

Developing Countries

1.1.5.8 At CAEP/6, FESG presented an analysis of the effects of CO_2-related charges on developing countries. This is the only study that was found within the scope of this task that specifically addresses impacts on developing countries. Though past CAEP analyses have established general differences between charging and trading systems, the paper is relevant regarding the different impacts on airlines from Annex 1 versus non-Annex 1 countries depending upon the relative coverage of such airlines in the system.

1.1.5.9 The analysis showed that the more routes covered by the system with competition between airlines from both developed and developing countries, the greater the impact on airlines from developing countries. Moreover, there are greater competitive distortion effects if the system only applies to airlines from Annex 1 countries.

1.1.5.10 The analysis demonstrated the importance of the definition of Annex 1 countries' emissions used in the assessment (e.g., emissions resulting from flights to and from Annex 1 countries, from flights departing from Annex 1 countries, or only from the flights of airlines based in Annex 1 countries), with the impact on airlines from non-Annex 1 countries being smaller as the application of the system is narrowed.

1.1.5.11 With the system applied only to airlines from Annex 1 countries, those from non-Annex 1 countries competing on covered routes benefit from the resulting increase in fares on such routes without having to face the increase in costs.

Effect on the market price of carbon

1.1.5.12 FESG had no conclusive findings on the effect on the price of allowances resulting from the addition of the aviation sector to an existing ETS.

1.1.6 **MODTF COD and FESG Forecast Baseline Reconciliation (Task F.06)**

1.1.6.1 The reconciliation of the 2006 baseline of the adjusted OAG (Official Airline Guide) database used in the development of the FESG CAEP/8 forecast and the MODTF Common Operations Database (COD) has been carried out covering both for the passenger and the freighter baseline data. Some issues were identified and an acceptable solution has been identified for all of them.

1.1.7 **Analysis of NO_x Stringency Options (Task F.07)**

1.1.7.1 The FESG established a NO_x Stringency Task Group (NSTG) to perform the economic assessment of the NO_x stringency options under consideration for CAEP/8. The results of this assessment are presented in paragraph 2.3.

1.1.8 **Production Cut-Off for Engine NO_x Standards (Task F.08)**

1.1.8.1 The FESG conducted an analysis to determine whether a NO_x production cut-off was required to support the CAEP/6 NO_x standard. The analysis showed that market forces are working and that non-compliant engines currently in production have been or very soon will be made compliant with the CAEP/6 NO_x standard, or have a very low volume of sales and will soon be out of production, and hence that there is no environmental impact. It was determined that greater than 99 per cent of in-production engines sold will meet the CAEP/6 NO_x requirements by 2009, and as a result there is no need for a production cut-off, since the environmental benefit from such a production cut-off would be negligible.

1.1.9 **Cost Analysis of the Production Cut-off for Engine NO_x Standards (Task F.09)**

1.1.9.1 The FESG conducted a related analysis to estimate the non-recurring cost impact of making affected engines compliant with a production cut-off to the CAEP/6 NO_x standard. Additional discussion on the subject of a production cut-off for engine NO_x Standards can be found in paragraph 2.2.4.

1.1.10 **Coordination with CAEP Secretary on GIACC Requests (Task F.10)**

1.1.10.1 In February 2009, the GIACC requested CAEP FESG to provide global aviation CO_2 emission projections to year 2050 in time for their meeting in May. This task built upon the deliverable produced by the FESG Projections Task Group described in paragraph 1.1.3. The FESG and MODTF responded jointly to this request and the outcomes of the analysis are reflected in the results presented in paragraphs 1.1.3.2 and 1.2.12.10.

1.1.11 **Scoping Study on Alternative Forecasting Approaches (Task F. 11)**

1.1.11.1 The FESG was tasked to conduct, with assistance from MODTF, a scoping study on alternative and/or supplemental approaches to the current consensus-based approach used to develop the FESG CAEP/8 forecast. The use of an alternative forecasting approach was proposed to address the following limitations of the previously-used forecasting methodology:

a) Short term perturbations

b) Constrained forecasting

c) Sensitivity analyses

d) Possible use of the MODTF Common Operations Database (COD) in the development of future fleet forecasts

1.1.11.2 The Co-Rapporteurs presented three possible options for modifying the FESG forecasting approach in the future: Current FESG Forecasting Approach Extended, Adaptation of Alternative Existing Tools or Forecasts for FESG Use, and Development of an FESG Model. The Co-Rapporteurs noted that any new forecasting approach proposed to supplement or replace the current FESG forecasting approach would need to go through a review process and that FESG would maintain the current forecasting approach until the new methodology is tested, reviewed and approved for CAEP's use.

1.1.11.3 Regarding the use of constrained forecasting, there are a number of issues to be considered, including the data requirements, the complexity of generating the forecast, definitions and conceptual issues. The Co-Rapporteurs noted that the use of a constrained forecast may be more appropriate at the local or regional level, as opposed to the global analyses typically conducted by CAEP. It was proposed that a one-off study be undertaken to assess the potential impact of constraints on the forecasting results. The Secretariat noted that a questionnaire is being sent to 150 airports regarding their current and anticipated capacity, and the future use of reliever airports.

1.1.11.4 On the possible use of the MODTF COD in the development of future fleet forecasts, FESG has identified a means to use this data with the Airbus Corporate Model that has historically been used. Therefore, it would be possible to prepare a forecast in the future that applies the MODTF COD to the same tools used in CAEP/8.

1.1.12 **Current FESG Forecasting Approach Extended (Option 1)**

1.1.12.1 A possible option would be to continue using the current FESG consensus-based forecasting approach to develop future forecasts, but to complement it with additional adjustments and/or analyses specially designed to address some of the aforementioned issues.

1.1.12.2 Of the options identified, this approach was found to require the lowest level of additional resources. Another advantage of such an approach is that FESG members are familiar with the current forecasting process. The costs in terms of additional resources and level of effort related to the implementation of this option would therefore be relatively low (e.g. as there would be no need to develop new models, etc).

1.1.12.3 The FESG FTG believes this option is the preferred option if the overriding considerations for the next CAEP work cycle are 1) delivery of the FESG traffic and fleet forecast in the shortest time frame; and 2) the minimum amount of resources available for the task.

1.1.13 **Adaptation of Alternative Existing Tools or Forecasts for FESG Use (Option 2)**

1.1.13.1 The FESG has made use of a number of existing models in the development of some components of the CAEP/8 forecast[1]. However, as these models are proprietary in nature, they are somewhat limited in the amount of information that can be disclosed on them and the ability to run sensitivity analyses around a wide range of assumptions and parameters influencing the forecasts.

1.1.13.2 An option that could be envisaged to address some of these issues would be to make use of alternative existing tools or forecasts (that are not currently used for forecasting within CAEP) and adapt them to generate the FESG forecast as a whole (i.e. the traffic and fleet forecasts for both passenger and cargo services) or in the development of some of its components.

1.1.13.3 The FESG Co-Rapporteurs noted that this "middle of the road" option is a preferred option if a primary consideration for the next CAEP work cycle is that FESG have the ability to better address the methodological concerns identified in this paper than with option 1, but there is insufficient time and/or resources in the next work cycle to fully develop the capabilities as envisioned in options 3 or 4. The use of existing tools/models and forecasts could enable the issues of short term perturbations and sensitivity analyses to be fully addressed. While avoiding the development costs associated with creating a new FESG forecasting model, there would be resource and timing implications.

1.1.14 **Development of an FESG Model (Option 3)**

1.1.14.1 Under this option, the FESG would develop its own model(s) to generate the forecast as a whole (i.e. the traffic and fleet forecasts for both passenger and cargo services) or a number of its components. This option, however, could only be envisaged if the necessary time and resources are made available to FESG.

1.1.14.2 The FESG Co-Rapporteurs stated that option 3 would be a preferred option if a) the customers of the FESG forecasts feel it is critical for the FESG to have the in-house capability to address the forecast methodology issues identified in this paper; b) the need for the delivery of the FESG traffic and fleet forecast early in the next CAEP work cycle is not pressing, and c) there are sufficient resources from Member states to develop the requisite models and systems. Switching to an econometric forecasting approach or system dynamic models would have a number of advantages, including improved transparency, while fully addressing the needs for analysis of short term perturbations and sensitivities. However, the main drawback is the substantial development costs involved with constructing a new forecasting approach from scratch. Challenges would arise from the availability, reliability and consistency of historical air traffic and socio-economic data for each world region. Building, validating and testing a new model can be expected to take at least one CAEP cycle and require significant resources, so that it would not be available until CAEP/10 at the earliest. Adopting option 3 would require

[1] The corporate model of Airbus specially calibrated with inputs and assumptions provided by FESG was used for the development of passenger fleet forecast. The freighter traffic and fleet forecasts were developed using a modified version of the approach used by Boeing to develop its own corporate forecast. And, the forecast for business jet aircraft was developed using the corporate model of Rolls-Royce. It is worth noting however that the contribution of FESG in terms of inputs and assumptions into the models used to develop the cargo and business jet aircraft forecasts was more limited.

additional help from outside FESG and funding for consultancy work made available by Member States. In addition the substantial resources required in developing new tools is likely to put at risk the production of new forecasts for CAEP/9 using the existing approach.

1.1.15 ICAO Databases and Forecasting Initiatives

Data Collection

1.1.15.1 In response to the GIACC's request to explore ways of enhancing the collection of data necessary to measure emissions performance, while taking into account existing guidance, the Tenth Session of the ICAO Statistics Division (STA/10) discussed a proposed form to collect fuel consumption data. STA/10 requested the feedback on the proposed form that included the initial recommendations to collect fuel consumption data in litres at the aircraft level, for international scheduled and non-scheduled traffic. STA/10 recommended that the form use the ICAO Statistical definitions, specifically the 100 kg average passenger mass, and that data on alternative fuels not be included on the form.

1.1.15.2 A new collection of aircraft movement data was also proposed for STA/10 consideration. In the interest of avoiding duplication of efforts, exploring synergies and pooling resources, the ICAO Secretariat is seeking the collaboration of CAEP and its MODTF with regard to updating and enhancing their 2006 COD, with the intention to start collecting 2010 data in 2011. The creation of one harmonized, global aircraft movement database would enable the Secretariat to perform traffic analyses that address the changing requirements in air traffic management and air navigation for potential applications, such as safety and efficiency assessments in support of, for instance, the performance-based navigation (PBN) concept. The implementation of the proposed data collection would require active support from Member States and their air navigation services providers (ANSPs). The aircraft movement that is currently collected by the Secretariat is not useful for safety and environmental analysis.

New ICAO Forecasting Methodology

1.1.15.3 The Secretariat has initiated development of new passenger and cargo traffic forecasts for the period 2010 to 2030 that could be extended to 2040. The initial forecast will be available in 2010. It applies a bottom-up econometric approach at the route-group level that will be built up to the global level. The forecast is being derived through the current data collection that covers 92 per cent of worldwide traffic and economic variables from the ICAO yield database. The forecast will be generated for the following nine regions: North America, Latin America/Caribbean, Europe, Middle East, Africa, Southwest Asia, China, North Asia, and Pacific/Southeast Asia.

1.1.16 Discussion and Conclusions

1.1.16.1 The meeting expressed its appreciation for the efforts of the FESG and their collaboration with MODTF to deliver coordinated responses on a number of tasks. The meeting approved the all of the products of FESG, including the forecast presented in Paragraph 1.1.2.

1.1.16.2 A member asked for a column on biofuels to be included in the data collection form.

1.1.16.3 A member noted that by using the FESG unconstrained forecast many airports in Europe and the US were shown to significant exceed capacity in the future scenarios. In those regions, it is unlikely that many capacity projects will be complete by 2036. The meeting supported the proposal for a sensitivity analysis of the impacts of using a constrained forecast and recommended that FESG and MODTF undertake this activity. This matter will be further discussed in Agenda Item 5.

1.1.16.4 The meeting noted that significant resources from Europe and US had been expended the on development of the COD and that the current agreements limit use of the COD to CAEP. The meeting agreed that should a new forecast be undertaken, the MODTF COD should be used as the baseline.

1.1.16.5 Without consideration to the future work of FESG, there was broad support for the development of proposed forecasting approach "Option 1." The future requirements of a forecast from FESG will be discussed under Agenda Item 5.

1.2 **REPORT OF THE MODTF**

1.2.1 The Co-Rapporteurs of MODTF presented the Task Force's report on activities since CAEP/7. Many of MODTF's tasks were primarily related to the following two areas: model and database evaluation, and assessment.

1.2.2 Due to the complexity of the CAEP/8 Work Programme, and the numerous cross-cutting issues between the various CAEP working groups, the groups took deliberate action to ensure sufficient coordination. This included frequent reviews of activities that required coordination and jointly reporting on those activities to each of the Steering Group meetings. Coordination among the groups typically involved the handoff of technical input to MODTF from the other Working Groups and FESG with MODTF then responding with initial findings and the results of analyses. This level of coordination proved to be an effective means of advancing the work.

1.2.3 The model evaluation, including related database development were preparatory tasks for MODTF, providing the foundation for the CAEP/8 assessment tasks. The model evaluation process was dependent on the conduct of sample problems, where a primary objective was to assess the models' and databases' state of readiness for conducting actual analyses. The model and database evaluation tasks are covered in more detail in paragraph 1.2.10.

1.2.4 MODTF completed an Environmental Goals Assessment that presents global trends for 2006, 2016, 2026 and 2036[2] for a number of scenarios which encompass a range of aircraft technology and operational improvements. This assessment was conducted with consistent input databases and assumptions across the three modelling domains: noise, local air quality, and greenhouse gas emissions. Harmonization of assumptions and the use of common airport, fleet and operations input data across the three modelling domains provided, for the first time, the ability to study the interrelationships between noise, LAQ and GHG results. This also helped satisfy the requirement to transition to a more comprehensive approach. The results of the environmental goals assessment indicated that even under the assumption of "optimistic technological and operational advances", CO_2 and NO_x emissions from aircraft will continue to increase through 2036. The assessment results were presented in more detail in a later part of this agenda item.

1.2.5 An international workshop was convened on assessing the impacts of noise, local air quality and greenhouse gases. This workshop was held the week of 29 October 2007 with the final report

[2] Fuel burn results are presented out to 2050 for consistency with data provided to the Group on International Aviation and Climate Change (GIACC).

being presented to the Steering Group in 2008. This workshop assessed, *intra alia*, the environmental need for emissions reduction from technology. The workshop noted that significant uncertainties remain and additional efforts were undertaken by the Impacts Ad-Hoc group mentioned.

1.2.6 Follow-on activity was carried out by an ICAO-led Impacts Ad Hoc Group. The results of this follow-on activity are presented in paragraph 1.3.13.

1.2.7 MODTF was asked to assist the CAEP Secretariat with reporting on CAEP/7 Goals to the ICAO Assembly. This task was completed early in the work cycle, with results reflected in the CAEP 2007 Environmental Report.

1.2.8 MODTF conducted a NO_x Stringency Policy Assessment, by working closely with FESG to ensure a seamless transfer of the environmental modelling information for use in the economic cost-effectiveness assessment. This assessment reflects the efforts by MODTF to transition to a more comprehensive approach to assess proposed actions. The results of this assessment are presented in paragraph 2.3.

1.2.9 MODTF provided input to both GIACC-3 and GIACC-4. For GIACC-3, MODTF provided preliminary results of the Environmental Goals Assessment. For GIACC-4, MODTF working directly with FESG, prepared a paper projecting aircraft fuel usage out to 2050. MODTF also provided GIACC-4 with updated results of the Environmental Goals Assessment, including information on fuel efficiency.

1.2.10 **Model and Database Evaluation**

1.2.10.1 The Co-Rapporteurs of MODTF presented the results of the Task Force's model and database evaluation activities. The aim of this evaluation was to inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis (e.g., stringency, CNS/ATM, market-based measure), and to understand any potential differences in modelling results.

1.2.10.2 Evaluation teams were established for each of the modelling areas: noise, local air quality, greenhouse gas emissions, and economics. They developed a methodology to ensure consistency in the model evaluation process across the four modelling areas.

1.2.10.3 The evaluation methodology began with a consideration of the following main characteristics or requirements of a robust model (including databases):

1) Capabilities

— Does the model do what is needed to answer the potential questions posed by CAEP?
— What are the limitations of the model?
— What new capability does the model bring to policy assessment? Does this capability bring added value?
— How well can the model frame quantitative estimates of uncertainty as part of the output?
— Conduct sensitivity tests to understand the tool structure, as well as the main sources and degree of uncertainty.

2) Data requirements for FESG of the noise, local air quality, and GHG tools (the requirements for the economic tools are addressed in FESG documentation).

— Does the tool produce the noise, emissions, and fuel flow data required by FESG for the economic analyses of the CAEP/8 policy studies?
— Does the tool generate the data in the format required by FESG?

3) Methodologies

— How does the model work, and does it comply with applicable standards?
— What data are required?
— Where do these data come from?
— How easy is it to change assumptions, baseline data, scenarios, etc.?

4) Readiness

— What is the likelihood that a tool under evaluation will be ready in time for application to the CAEP/8 policy studies?
— Assess the labour and funding commitment to the development.
— Assess the state of software development.
— Assess the maturity of the methodologies.
— Assess the maturity of the models V&V activities.
— Assess the number of innovations that have yet to be incorporated and tested.

5) Transparency

— Are system architecture, functional requirements, algorithm description, data description, and other software design related documents available to CAEP?
— Are there technical reports, which describe research and V&V supporting the algorithms and methodologies, available to CAEP?

6) Fidelity

— Are the methods and algorithms to generate the noise, emissions, and fuel use data reasonable?
— Where the requirement is to assess interdependencies, does the tool reasonably represent trends and relationships among environmental factors?

7) Usability

— Who is to use the model, and what training is required?
— What is the level of accessibility and availability?
— What role is CAEP to have during input processing and running?
— How will MODTF interface with FESG during processing and running?

8) Validation and verification (V&V)

— Is there a “gold standard” and how does the tool compare?

1.2.10.4 Not all of these requirements were required to be addressed in detail, but a comparison of key elements among candidate models helped identify areas that required further investigation by the model and database evaluation team.

1.2.10.5 The models were then used to assess two sample problems: the effects of reduced thrust takeoff and the effects of hypothetical NO_x stringency. One of the goals of the sample problems was to advance candidate model evaluation and development by practicing on a set of problems that are similar to those that were considered as part of the CAEP/8 work programme. The practice analyses were accompanied by a rigorous assessment process, so that the strengths and deficiencies in the models could be identified, and appropriate refinements and improvements implemented. This ensured that the models were sufficiently well understood and robust to support a broad range of CAEP/8 analyses.

1.2.10.6 All of the candidate models in each domain area and all contributing databases were found to be suitable to support assessment of one or more of the current and likely future CAEP assessments (e.g., CAEP/8 NO_x Stringency and Environmental Goals Assessment). Where models are shown to need adaptation or major change to meet other CAEP requirements, there does not appear to be any reason why such adaptations and changes could not be made, should the model submitters wish to do so. These conclusions were accepted by the Steering Group in 2008.

1.2.10.7 The Co-Rapporteurs noted that each model and database has its strengths and weaknesses. The use of multiple models provided MODTF insight into sensitivities of the results. The Co-Rapporteurs noted, however, that consideration should be given to the value added to the work programme by introducing additional models for evaluation. The models and databases have not yet been evaluated against the requirements of assessing the effects of operational changes. Further evaluation work will be required if a detailed operational analysis is required as part of the future CAEP programme.

1.2.10.8 Table 11 lists the tools that were found by MODTF to meet those criteria for each of the modelling domains: noise, local air quality, greenhouse gas emissions, and economics.

1.2.11 **Discussion and Conclusions**

1.2.11.1 The meeting congratulated MODTF on its significant advances in modelling capabilities and demonstration of a transition to a more comprehensive approach to assess proposed actions.

1.2.11.2 The meeting agreed that the MODTF model and database evaluation process presented satisfies the requirement to better inform CAEP on which tools are sufficiency robust, rigorous and transparent, and appropriate for which analysis and on the sufficiency of the databases.

1.2.11.3 A Member expressed support for the recommendation by the Co-Rapporteur that CAEP should exercise restraint when considering additional models if a sufficient number have already been approved that provide similar results. New models PolEmiCa and PEGAS were proposed by the Ukraine and the Russian Federation, respectively. The consideration of new models is discussed under Agenda Item 5.

Table 11. Summary of evaluated models and databases.

Modelling Area	Model / Database Name	Release	Release Date	Sponsoring Organization
Noise	AEDT/MAGENTA	1.4	2009	US FAA
	ANCON2	2.3	N/A	UK DfT
	STAPES	1.1	December 2008	EUROCONTROL
Local air quality	ADMS-Airport	2.5	June 2009	UK DfT
	AEDT/EDMS	1.4	2009	US FAA
	ALAQS-AV	NOV08	November 2008	EUROCONTROL
	LASPORT	2.0	March 2009	Swiss Federal Office for Civil Aviation (FOCA) German Ministry of Transport (BMVBS)
Greenhouse Gas	AEDT/SAGE	1.4	2009	US FAA
	AEM III	2.0	March 2009	EUROCONTROL
	Aero2k	N/A	N/A	UK DfT
	FAST	N/A	N/A	UK DfT
Economics	APMT	4.0.3	2009	US FAA
	NOx Cost	4.0	2009	FESG
All	Airports Database	1.5.4	November 2008	US FAA, EUROCONTROL
All	Common Operations Database	2.0	February 2009	US FAA, EUROCONTROL
All	2006 Campbell-Hill Fleet Database	CAEP/8	December 2007	WG1 / WG3
All	2006 Campbell-Hill Fleet Database Extension	CAEP/8	July 2008	US FAA
All	Population Database	1.0	9 March 2009	US FAA, EASA
LAQ, GHG	ICAO aircraft engine emissions databank (EDB)	16A	5 February 2009	UK DfT, WG3
All	ANP - Aircraft Noise and Performance	1.0	12 May 2006	EUROCONTROL
All	Base of Aircraft Data (BADA)	3.6	2004	EUROCONTROL
All	Forecasting and Operations Module (FOM)	2.3.2	14 February 2009	US FAA
All	FESG Traffic Forecast (pax. + cargo)	CAEP/8	July 2008	ICAO Secretariat, FESG, ICCAIA
All	FESG Retirement Curves	CAEP/8	July 2008	ICCAIA, FESG
All	Growth & Replacement Database	7	30 January 2009	ICCAIA, WG1, WG3

1.2.12 **Goals Assessment Results**

1.2.12.1 The Co-Rapporteurs of MODTF presented results from the assessment of environmental goals. They noted that to accomplish this analysis close coordination was needed between FESG, WG1, WG2, WG3, and MODTF. Aircraft noise, NO_x emissions, particulate matter emissions, aircraft fuel consumption, and commercial aircraft system fuel efficiency (CASFE) were evaluated.

Aircraft Noise

1.2.12.2 Four scenarios were used to estimate the population exposed to various levels of aircraft noise:

Scenario 1 (*CAEP7 Baseline*)[3]: This scenario includes the operational improvements necessary to maintain current efficiency levels, but does not include any technology improvements beyond those available in current (2006) production aircraft.

Scenario 2 (*Low Aircraft Technology and Moderate Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes noise improvements of 0.1 EPNdB per annum for all aircraft entering the fleet from 2013 to 2036, and additional fleet-wide moderate operational improvements of 2% for population[4] inside DNL 55, 60, and 65 contours. For aircraft entering the fleet between 2008 and 2013, no noise-related technology improvement was applied.

Scenario 3 (*Moderate Aircraft Technology and Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes noise improvements of 0.3 EPNdB per annum for all aircraft entering the fleet from 2013 to 2020, 0.1 EPNdB from 2020 to 2036, and additional fleet-wide moderate operational improvements of 2% for population inside DNL 55, 60, and 65 contours. For aircraft entering the fleet between 2008 and 2013, no noise-related technology improvement was applied.

Scenario 4 (*Advanced Aircraft Technology and Moderate Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes noise improvements of 0.3 EPNdB per annum for all aircraft entering the fleet from 2013 to 2036, and additional fleet-wide moderate operational improvements of 2% for population inside DNL 55, 60, and 65 contours. For aircraft entering the fleet between 2008 and 2013, no noise-related technology improvement was applied.

[3] Since Scenario 1 is not considered a likely outcome, it is purposely depicted in all graphics with no line connecting the modelled results in 2006, 2016, 2026 and 2036, for all parameters – noise, NOx, PM, fuel burn and CASFE.
[4] Operational improvements are only likely to change the shape of the contour, not the overall size.

1.2.12.3 Figure 2 provides MODTF consensus results for the total global population exposed to aircraft noise above 55DNL for 2006, 2016, 2026 and 2036. The 2006 baseline value is about 21.2 million people. In 2036, total population exposed ranges from about 26.6 million people with Scenario 4, to about 34.1 million people with Scenario 2. For comparative purposes, Figure 3 shows the range of results for total global population exposed above 55DNL for scenarios based on the FESG central and low-demand forecasts. Scenario 1 was not considered by MODTF to be a realistic outcome.

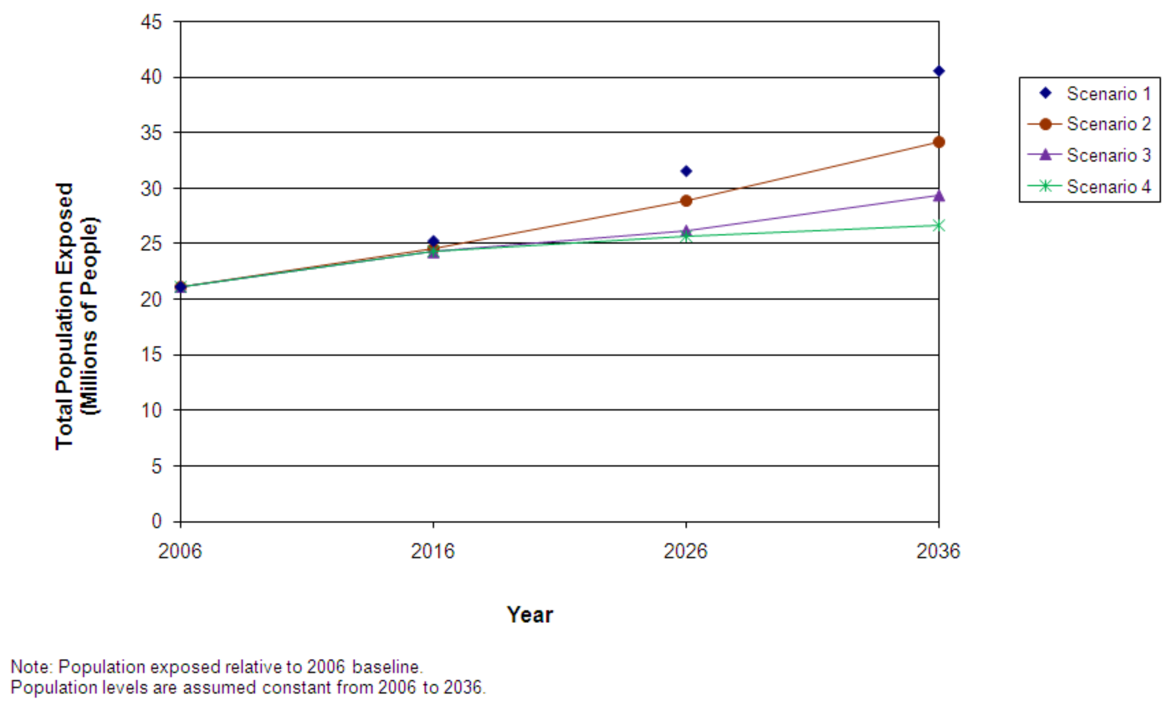


Figure 2: Total Global Population Exposed to >55 DNL Aircraft Noise
(Based on FESG Central Forecast)

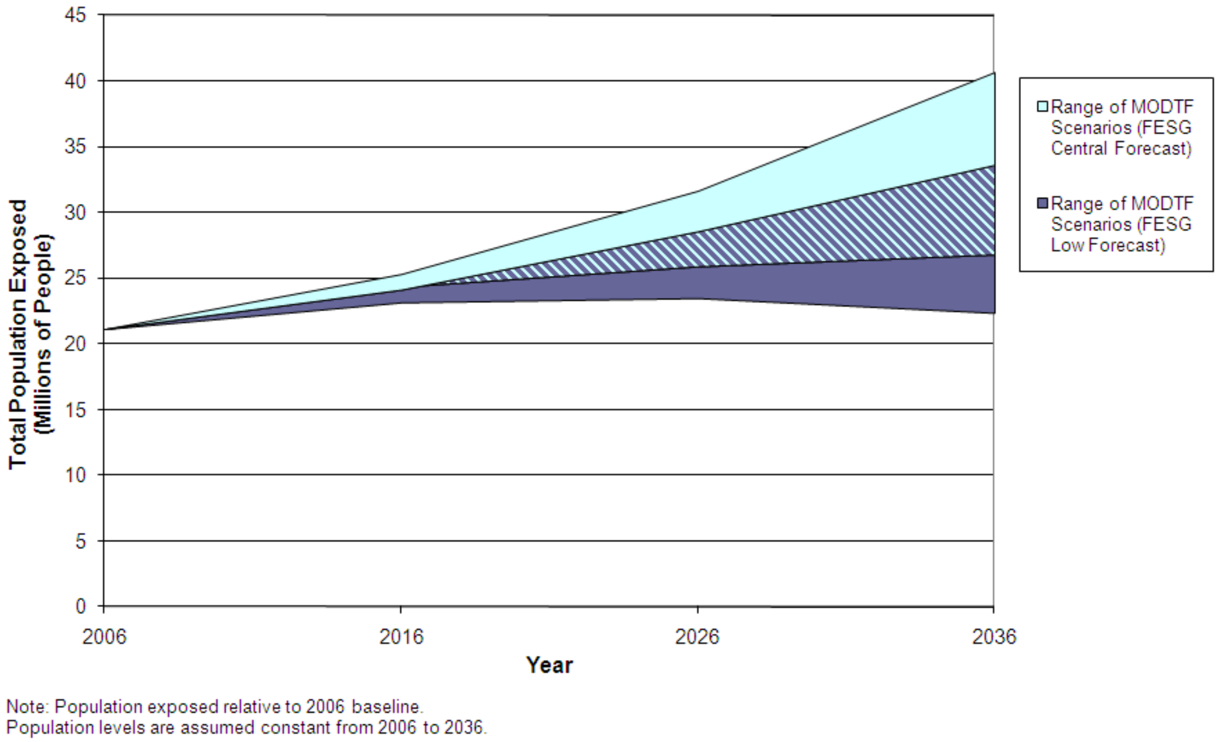


Figure 3: Total Global Population Exposed to >55 DNL Aircraft Noise Range of Scenarios
(Based on FESG Central and Low Forecasts)

NO_x and Particulate Matter (PM) Results Below 3,000 Feet

1.2.12.4 Figure 4 provides MODTF consensus results for global NO_x emissions below 3,000 ft for 2006, 2016, 2026 and 2036. The 2006 baseline value is about 0.25 million metric tonnes (Mt). In 2036, total NO_x ranges from 0.52Mt (1kg x 109), with Scenario 3, to 0.72 Mt with Scenario 2. Figure 5 shows the range of results for global NO_x below 3,000 ft for scenarios based on the FESG central and low-demand forecasts. Figure 6 provides a global map of 2006 aircraft NO_x emissions below 3,000 ft. As with Figures 3 and 4, the global map depicts aircraft NO_x only at an airport, not in a city. Paragraph 1.2.14 puts aircraft emissions in context with other aviation-related emissions at an airport. Table 12 lists the assumptions regarding per cent operational improvements relative to 2006, by region. These improvements translated directly to improvements in NOx, PM, fuel burn, and CASFE.

Table 12. Per cent operational improvements relative to 2006, by region.

	2016		2026	
	Lower Bound	**Upper Bound**	**Lower Bound**	**Upper Bound**
North America	0	-2	0	-4
Europe	-2	-6	-3	-7
Central America	-1	-4	-2	-5
South America	-1	-4	-2	-5
Middle East	-2	-5	-3	-6
Africa	-4	-7	-5	-8
Asia/Pacific	-3	-6	-4	-7

1.2.12.5 Three scenarios were used to estimate aircraft NO_x emissions:

Scenario 1 (*CAEP7 Baseline*)[5]: This scenario includes the operational improvements necessary to maintain current operational efficiency levels, but does not include any technology improvements beyond those available in current (2006) production aircraft.

Scenario 2 (*Moderate Aircraft Technology and Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes NO_x improvements based upon achieving 50% of the reduction from the current NO_x emission levels to the CAEP/7 NO_x Goals by 2026, with no further improvement thereafter. This scenario also includes fleet-wide moderate operational improvements by region, as provided in Table 1, under “lower bound”.

Scenario 3 (*Advanced Aircraft Technology and Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes NO_x improvements based upon achieving 100% of the reduction from the current NO_x emission levels to the CAEP/7 NO_x Goals by 2026, with no further improvement thereafter. This scenario also includes fleet-wide advanced operational improvements by region, as provided in Table 1, under “upper bound”.

1.2.12.6 Figure 7 provides MODTF consensus results for global PM emissions below 3,000 ft for 2006, 2016, 2026 and 2036. The 2006 baseline value is 2,200 metric tonnes. In 2036, total global PM is projected to be about 5,800 metric tonnes with Scenario 2. Figure 8 shows the range of results for global PM below 3,000 ft for scenarios based on the FESG central and low-demand forecasts.

[5] Since Scenario 1 is not considered a likely outcome, it is purposely depicted in all graphics with no line connecting the modelled results in 2006, 2016, 2026 and 2036, for all parameters – noise, NOx, PM, fuel burn and CASFE.

1.2.12.7 Two scenarios were used to estimate aircraft PM emissions:

Scenario 1 (*CAEP7 Baseline*)[6]: This scenario includes the operational improvements necessary to maintain current operational efficiency levels, but does not include any technology improvements beyond those available in current (2006) production aircraft.

Scenario 2 (*Moderate Technology and Operational Improvements*): Due to the limited scientific understanding of aircraft engine PM emissions, WG3 accepted that MODTF incorporate no PM reduction or increase due to future technology. There are small improvements associated with this scenario due to the indirect contribution of technology-based fuel improvements plus second-order effects on fuel burn improvements associated with the operational efficiencies that were applied; however only one scenario is shown, as the differences between the scenarios are not graphically discernable. This scenario includes fleet-wide moderate technology and operational improvements by region, as provided in Table 12 (lower bound).

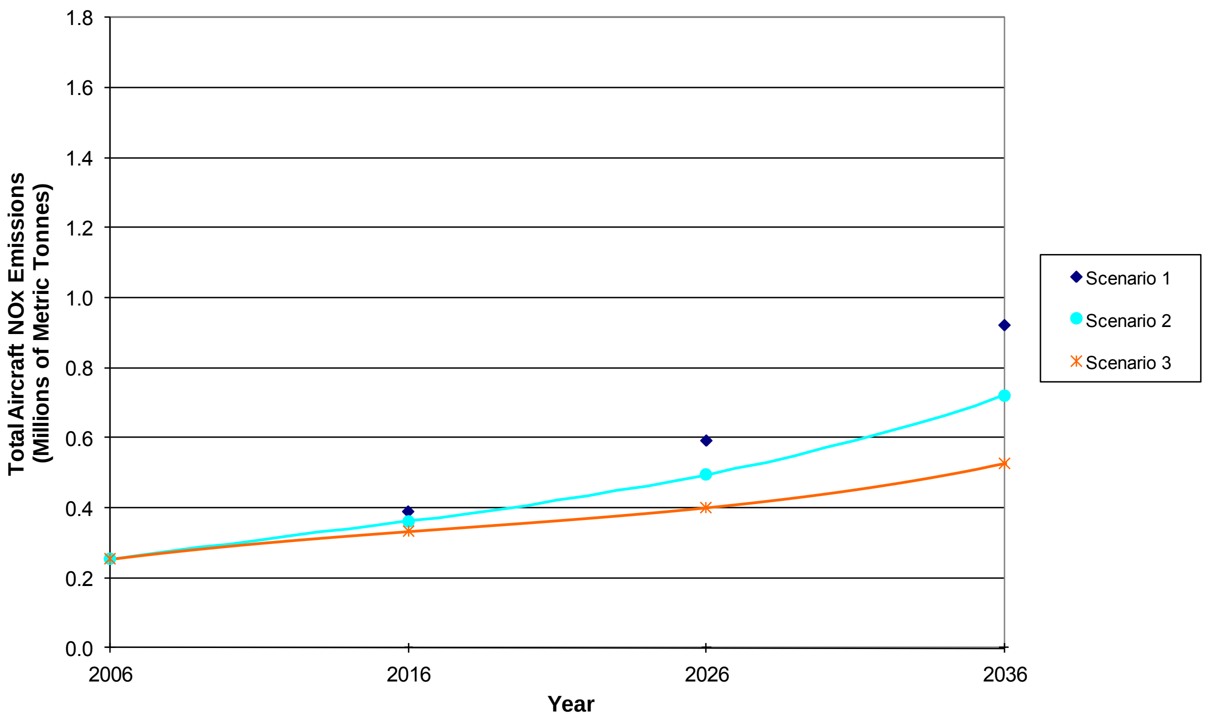


Figure 4: Total Global Aircraft NO_x Emissions Below 3,000 ft AGL
(Based on FESG Central Forecast)

[6] Since Scenario 1 is not considered a likely outcome, it is purposely depicted in all graphics with no line connecting the modelled results in 2006, 2016, 2026 and 2036, for all parameters – noise, NOx, PM, fuel burn and CASFE.

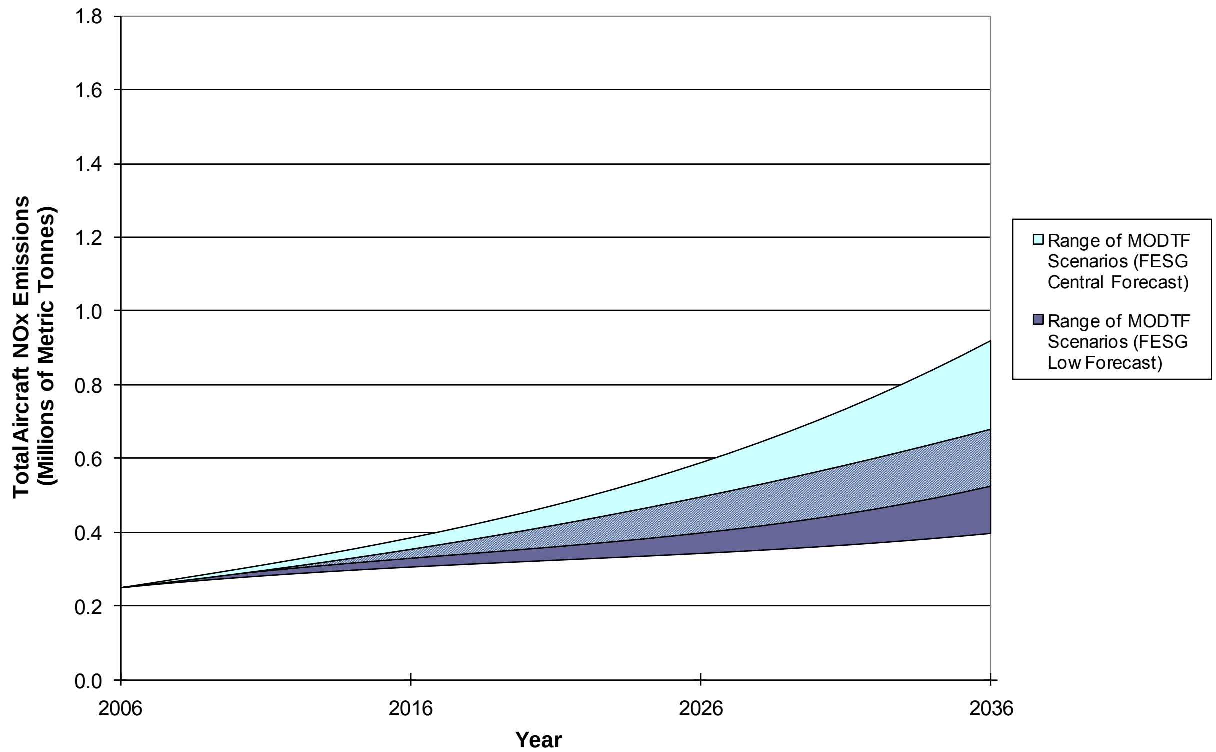


Figure 5: Total Global Aircraft NO_x Emissions Below 3,000 ft AGL Range of Scenarios
(Based on FESG Central and Low Forecasts)

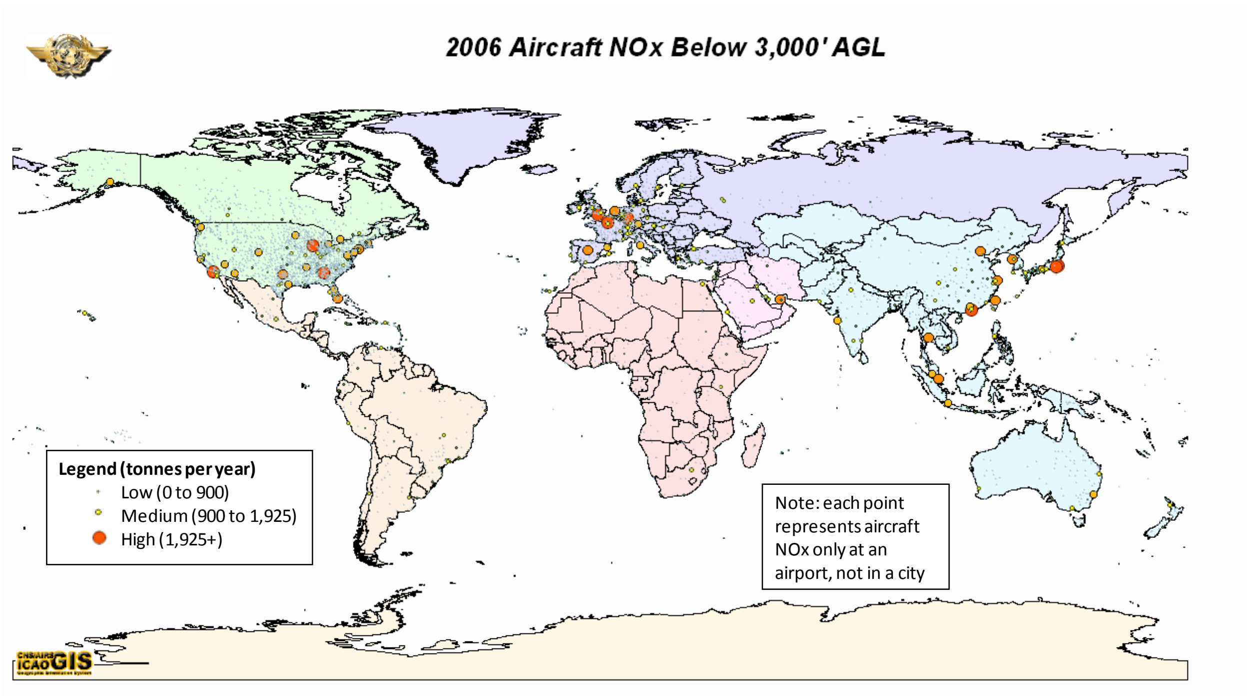
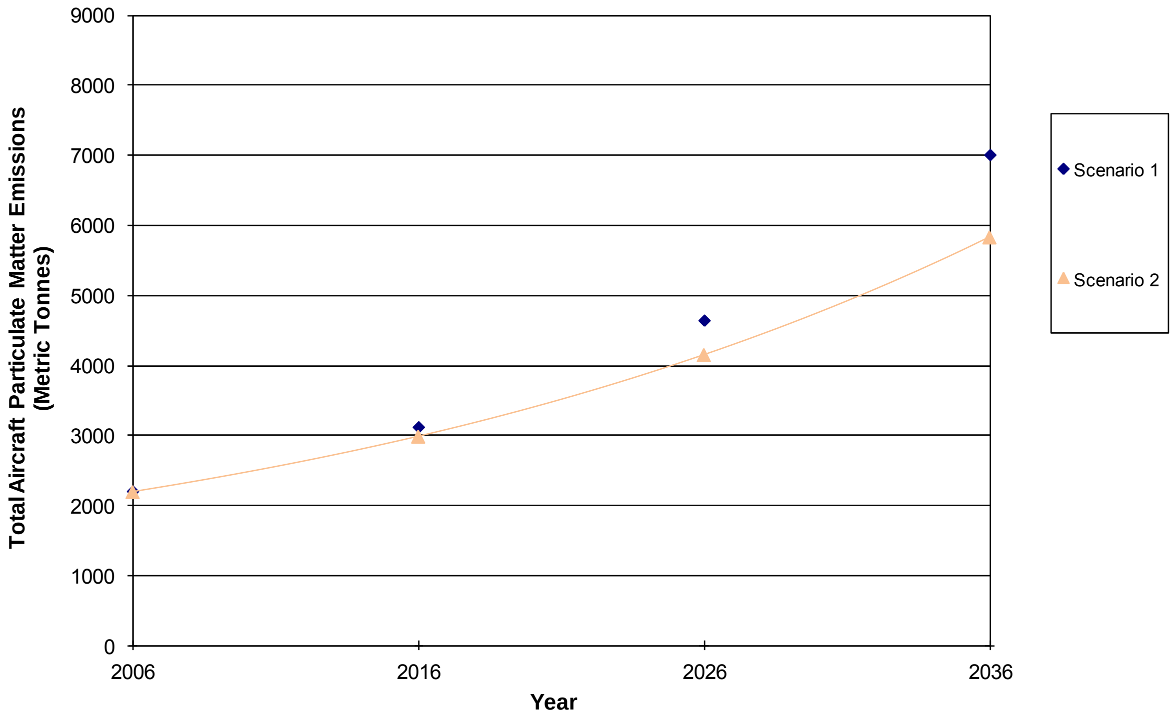


Figure 6: 2006 Airport-Aircraft NO_x Emissions Below 3,000 ft AGL



Note: Results were modelled using WG3 First Order Approximation (FOA) Version 3.0

Figure 7: Total Global Aircraft Particulate Matter Emissions Below 3,000 ft AGL
(Based on FESG Central Forecast)

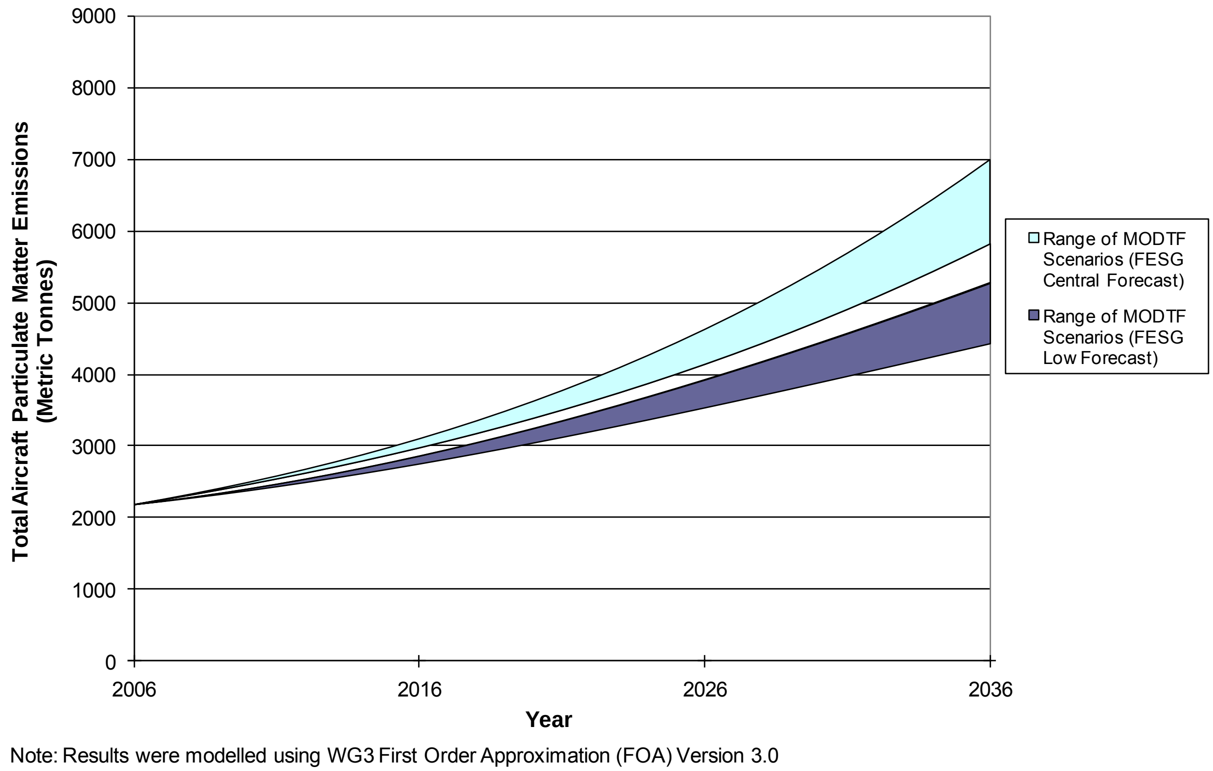


Figure 8: Total Global Aircraft Particulate Matter Emissions Below 3,000 ft AGL Range of Scenarios
(Based on FESG Central and Low Forecasts)

NO_x Results Above 3,000 feet

1.2.12.8 The scenarios assessed for NO_x above 3,000 ft were identical to those for NO_x below 3,000 ft. Figure 9 provides MODTF consensus results for global NO_x above 3,000 ft for 2006, 2016, 2026 and 2036. The 2006 baseline value is approximately 2.5 Mt. In 2036, total NO_x ranges from approximately 4.6 Mt in Scenario 3, to about 6.3 Mt in Scenario 2. Figure 10 shows the range of results for global NO_x above 3,000 ft for scenarios based on the FESG central and low-demand forecasts.

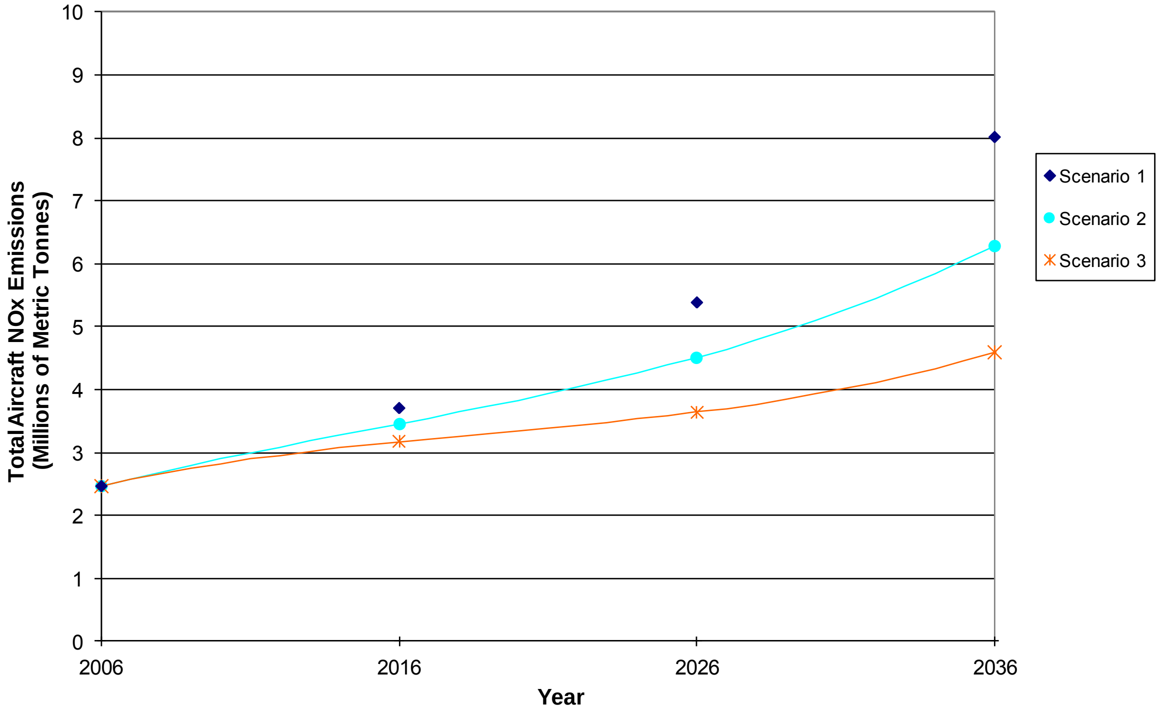


Figure 9: Total Global Aircraft NO_x Emissions Above 3,000 ft AGL
(Based on FESG Central Forecast)

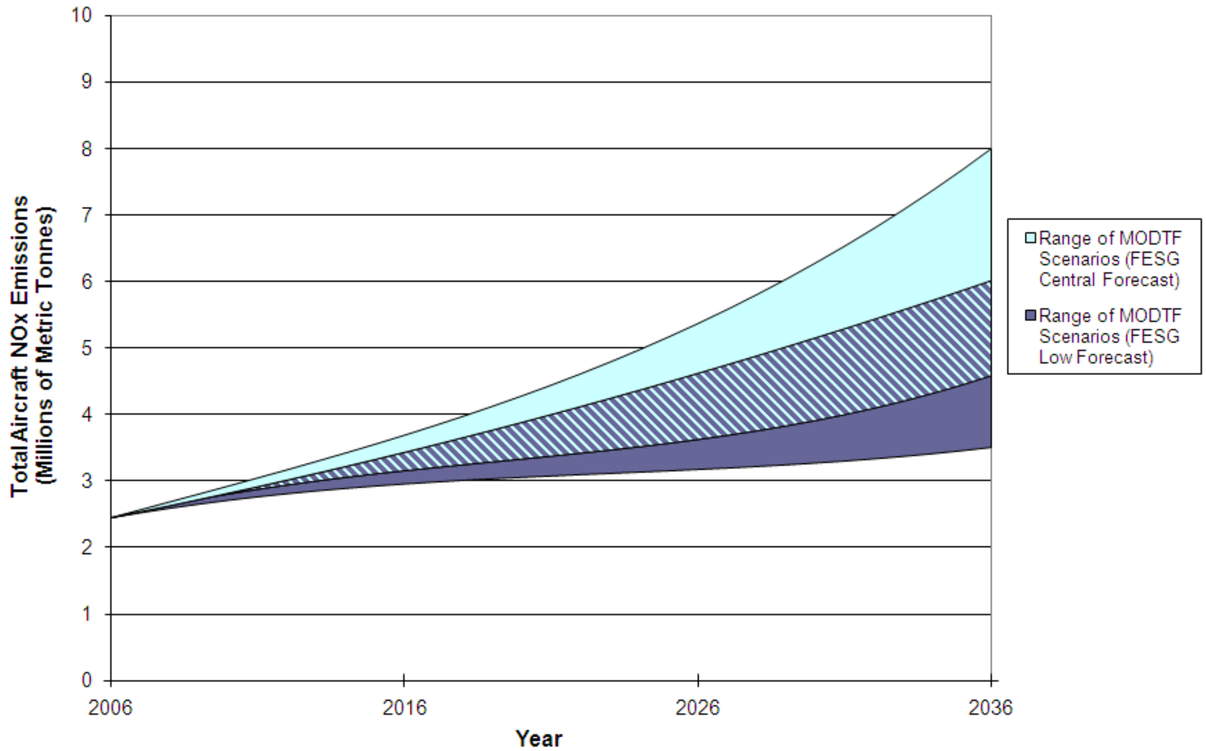


Figure 10: Total Global Aircraft NO_x Emissions Above 3,000 ft AGL Range of Scenarios
(Based on FESG Consensus and Low Forecasts)

Fuel Burn and Commercial Aircraft System Fuel Efficiency Metric (CASFE) Full-Flight Results

1.2.12.9 Five scenarios were used to estimate global full-flight fuel burn and CASFE:

Scenario 1 (*CAEP7 Baseline*)[7]: This scenario includes the operational improvements necessary to maintain current operational efficiency levels, but does not include any technology improvements beyond those available in current (2006) production aircraft.

Scenario 2 (*Low Aircraft Technology and Moderate Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 and prior to 2015, and 0.57 percent per annum for all aircraft entering the fleet beginning in 2015 to 2036. It also includes additional fleet-wide moderate operational improvements by region, as provided in Table 12, under "lower bound".

[7] Since Scenario 1 is not considered a likely outcome, it is purposely depicted in all graphics with no line connecting the modelled results in 2006, 2016, 2026 and 2036, for all parameters – noise, NOx, PM, fuel burn and CASFE.

Scenario 3 (*Moderate Aircraft Technology and Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes fuel burn improvements of 0.96 percent per annum for all aircraft entering the fleet after 2006 to 2036, and additional fleet-wide moderate operational improvements by region, as provided in Table 12, under "lower bound".

Scenario 4 (*Advanced Aircraft Technology and Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes fuel burn improvements of 1.16 percent per annum for all aircraft entering the fleet after 2006 to 2036, and additional fleet-wide advanced operational improvements by region, as provided in Table 12, under "upper bound".

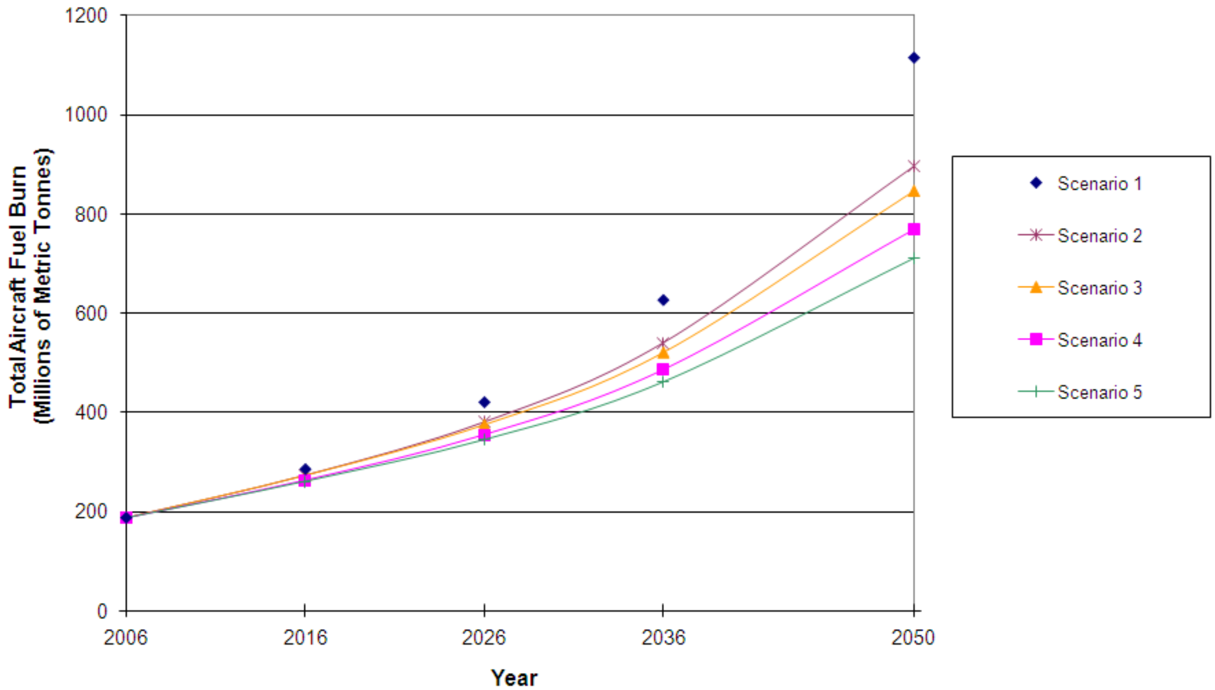
Scenario 5 (*Optimistic Aircraft Technology and Advanced Operational Improvement*): In addition to including the improvements associated with the migration to the latest operational initiatives, e.g., those planned in NextGen and SESAR (Scenario 1), this scenario includes an optimistic fuel burn improvement of 1.5 percent per annum for all aircraft entering the fleet after 2006 to 2036, and additional fleet-wide advanced operational improvements by region, as provided in Table 12, under "upper bound". This scenario goes beyond the improvements based on industry-based recommendations.

1.2.12.10 Figure 11 provides MODTF consensus results for global full-flight fuel burn for 2006, 2016, 2026, 2036 and 2050. The 2006 baseline value is 187Mt of fuel. In 2036, total fuel burn ranges from about 461Mt with Scenario 5, to about 541Mt with Scenario 2. Figure 12 shows the range of results for global full-flight fuel burn for scenarios based on the FESG central and low-demand forecasts. Figure 13 provides a global map of 2006 total aircraft full-flight fuel burn. This global map, which is based on Great Circle routing, depicts fuel burn in 1-degree-by-1-degree grid cells, aggregated for all altitudes within a particular cell. Figure 14 provides the percentage of global aircraft full-flight fuel burn attributed to international and domestic traffic.

1.2.12.11 The baseline value of 187Mt in 2006 does not include fuel burn associated with aviation-related operations (e.g., auxiliary power units, ground support equipment, etc.) or fuel burn by VFR[8] flights. Non-scheduled flights in regions for which radar data are not available were also not accounted for. Together fuel burn from aviation-related operations, VFR flights and non-scheduled flights may amount to approximately 10 to 12 percent additional fuel burn. For comparison, the International Energy Agency (IEA) reported aviation fuel use of 236Mt[9] for 2006. This value includes military and general aviation. The AERO2k 2002 Inventory calculated military, general and commercial aviation usage separately, with military and general aviation comprising approximately 12 to 13 percent of the total. Taking into account these two approaches to reporting global aviation fuel burn, the actual value of fuel burn for commercial aviation in 2006 would appear to lie in the range of 200 to 205Mt.

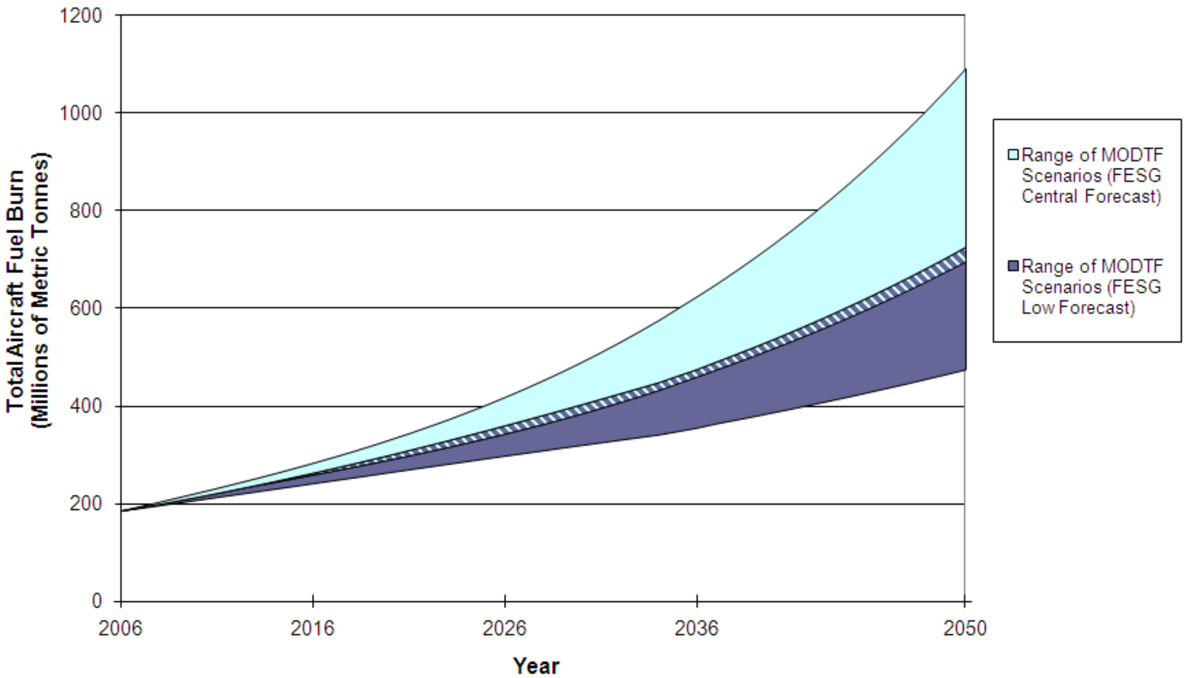
1.2.12.12 Figure 15 presents the global CASFE results for the years 2006, 2016, 2026 and 2036. The 2006 baseline value is 0.32 kg/tonne-km. In 2036, global CASFE ranges from about 0.25 in Scenario 2, to about 0.21 in Scenario 5. Note: lower CASFE values represent more efficient operations. Also depicted in Figure 15 by a dashed line is the Council aspirational goal.

[8] Visual Flight Rules
[9] IEA kerosene fuel sales data



Note: Results were modelled for 2006, 2016, 2026, and 2036, then extrapolated to 2050.

Figure 11: Total Global Aircraft Fuel Burn, Combined International and Domestic
(Based on FESG Central Forecast)



Note: Results were modelled for 2006, 2016, 2026, and 2036, then extrapolated to 2050.

Figure 12: Total Global Aircraft Fuel Burn, Combined International and Domestic Range of Scenarios

(Based on FESG Central and Low Forecasts)

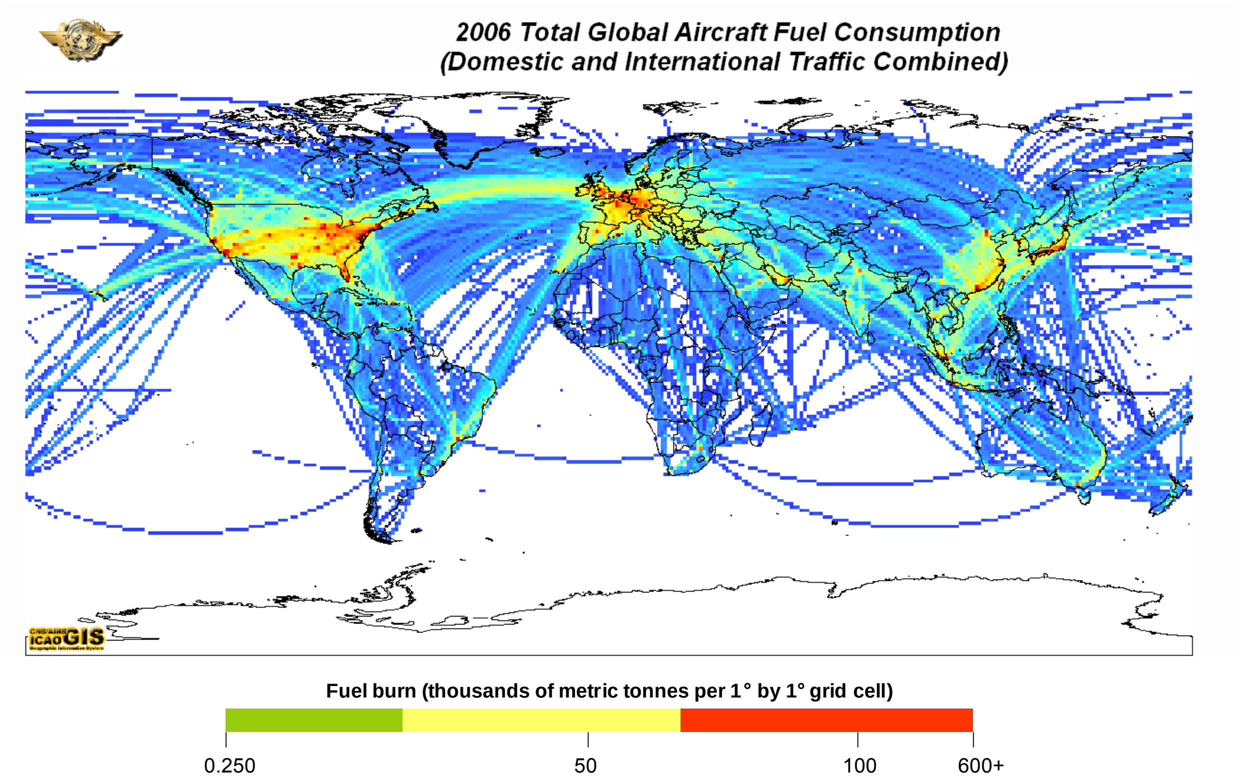


Figure 13: 2006 Total Global Aircraft Fuel Burn, Combined International and Domestic Great Circle Routing Depicted

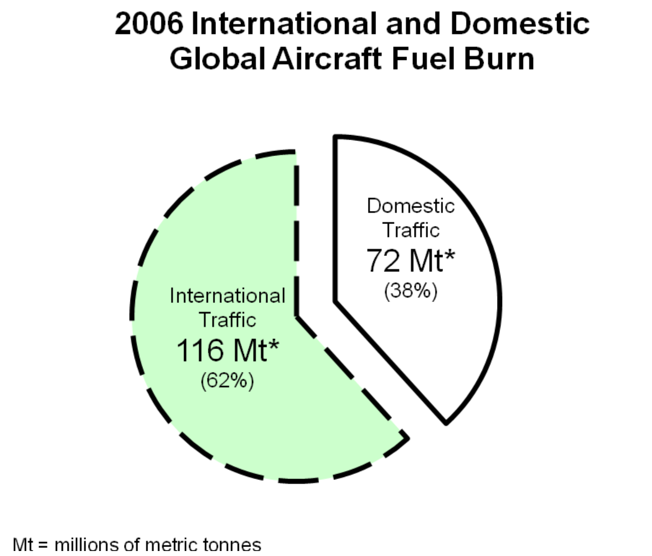


Figure 14: 2006 International and Domestic Global Aircraft Fuel Consumption

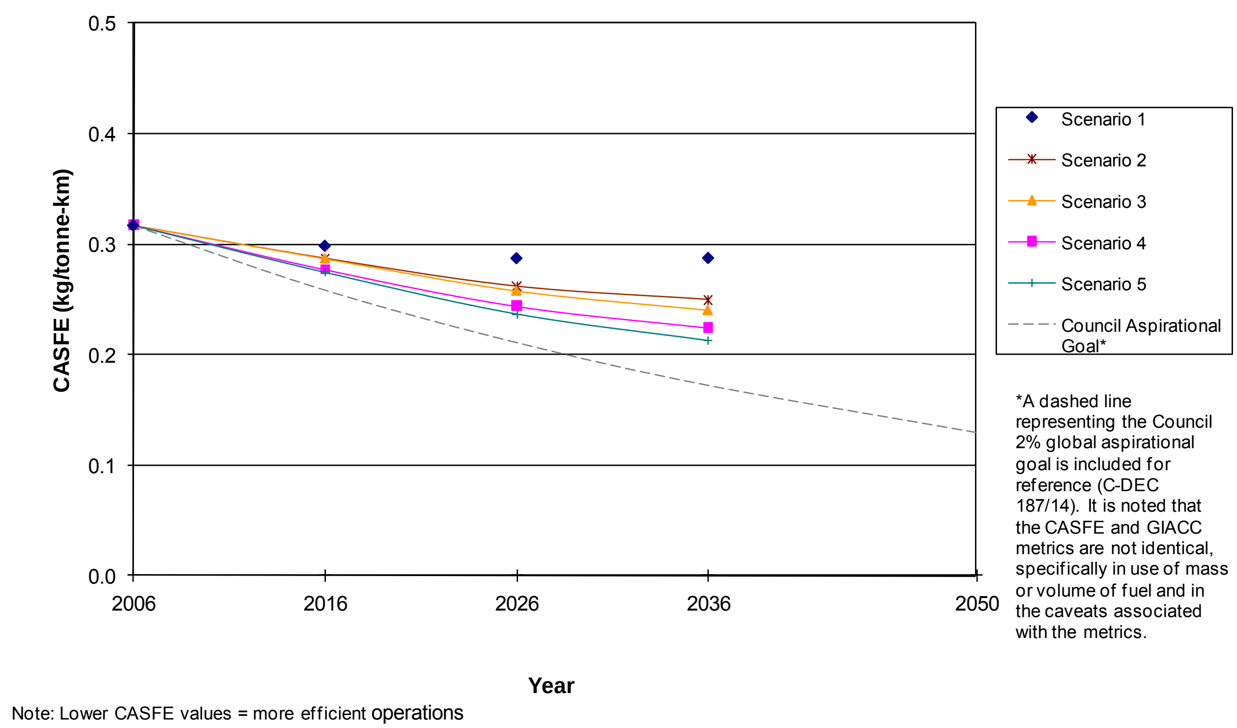


Figure 15: Global Commercial Aircraft System Fuel Efficiency, CASFE
(Based on FESG Central and Low Forecast)

1.2.13 **Comparison with CAEP/7 Environmental Trends**

1.2.13.1 The Co-Rapporteurs noted that differences in results between the analyses undertaken during CAEP/7 and those conducted during CAEP/8 exist for a number of reasons including: changes in the models, input assumptions, input databases, and the use of a new forecast. The results computed for CAEP/8 are considered more robust due to significant improvements in the underlying models and databases used. To simplify the comparison, the data modelled in 2005, 2015, and 2025 in CAEP/7 were compared with those modelled in CAEP/8 for 2006, 2016 and 2026.

1.2.13.2 For noise, the two sets of results were close, with differences in population exposed to greater than 55 dB DNL being within 5% for all years. The population values were lower in the CAEP/8 modelling for the first ten years, and ended up being higher by 2025/2026, likely indicative of the faster growth during this time period exhibited in the CAEP/8 FESG forecast and not to the upgrade in the underlying population database. While no PM computations were computed in CAEP/7 the CAEP/7 and CAEP/8 NO_x values below 3,000 ft were within 20% of one another. The CAEP/7 and CAEP/8 NO_x values above 3,000 ft were also within 20% of one another. For global fuel burn, the CAEP/7 and CAEP/8 values were within 10%, with a noticeably similar trend to that observed for noise, where the values were lower to 2015/2016 in the CAEP/8 modelling, but higher in 2025/2026. Again, this is likely due to the faster growth during this time period exhibited in the CAEP/8 FESG forecast, as compared with that of CAEP/7.

1.2.14 **Putting the Results in Context**

1.2.14.1 The MODTF Co-Rapporteurs presented additional information in order to put the emissions results into context with other sources.

1.2.14.2 Across the size spectrum of airports, aircraft emissions contribute between 70 to 80% of total airport NO_x emissions.

1.2.14.3 The contribution of airport emissions to the overall emissions loading in the vicinity of airports is dependent upon the emission sources surrounding the airport. For a typical urban environment, airport emissions were found to represent approximately 10% of total regional emissions[10] in the vicinity of airports, whereas in more rural environments airport emissions would tend to be a higher percentage.

1.2.14.4 At the local air quality level, the Co-Rapporteurs explained that mass emissions from airport sources are only a metric for comparison purposes. To understand the influence on ambient air quality, airport mass emissions must be converted to ambient concentrations. Five primary aspects make it difficult to convert airport emissions to ambient local air quality concentrations close to airports. They are:

a) location and dynamics of the emitting source;

b) spatial and temporal distribution of all emission sources;

c) meteorological input information;

[10] The region referred to here should not be confused with CAEP regions, but refers to the local communities surrounding the airport, e.g., 50 km x 50 km.

d) applied atmospheric boundary layer model; and

e) algorithm used in a dispersion model to convert emissions to concentrations.

1.2.14.5 The incremental contribution in ambient pollutant concentrations from airport emissions decreases the further one travels away from the airport. Each airport's contribution is unique, given the surrounding urbanization/industrialization and meteorological conditions within the vicinity of the airport.

1.2.14.6 A MODTF Context Ad-hoc Group was formed to research available data on CO_2 emissions from other transport modes to support the presentation of results for the CAEP/8 Trends Assessment. The Ad-hoc Group considered that for the purposes of the CAEP/8 Environmental Goals Assessment, the percentage split of CO_2 emissions for 2006, as shown in Figure 16, served the need to put aviation GHG emissions into context with other transport modes, as it would have been difficult to determine how the relative contributions would differ for the future scenarios. There were only small differences for aviation as a percentage of the total transport CO_2 emissions among the different data sources, with a contribution of between 11 and 12 percent.

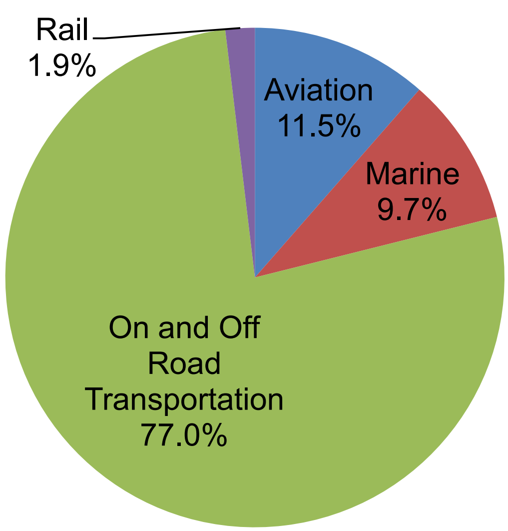


Figure 16: 2006 Transportation-related CO_2 Emissions Sources[11]

1.2.15 **Comparisons Across Modelling Domains**

1.2.15.1 The CAEP/8 Environmental Goals Assessment was conducted with consistent databases and assumptions across the three modelling domains. Harmonization of assumptions and the use of common airport, fleet and operations (i.e., the Common Operations Database) input data across the three modelling domains provides CAEP, for the first time, the ability to study the interrelationships between noise, LAQ and GHG results.

[11] Percentages shown are based on the average of the 2006 IEA and UNFCCC data in CAEP/8_IP8 Table 8.

1.2.16 **Discussion and Conclusions**

1.2.16.1 The meeting expressed its appreciation for the detailed environmental assessments and in particular thanked the group for the consideration of how best to communicate the results of their analysis. The meeting noted that the individual models within each domain (noise, local air quality, and greenhouse gasses) had different levels of uncertainty. The noise models produced nearly identical results, the fuel burn variability between the models was less than 5 per cent, and the local air quality NO_x results varied up to 15 per cent from one model to the other.

1.2.16.2 When comparing the results to CAEP/7 these uncertainties combined with the use of a new forecast explain the majority of the differences between CAEP/7 and CAEP/8.

1.2.16.3 The meeting noted the significant effect of the traffic forecast on the results. As is illustrated in Figure 3, the most aggressive technology and operational improvement combined with the low demand forecast showed almost no change in population exposed to aircraft noise through 2036 compared to the increase in noise exposure over the same time period for the central demand case. While not as dramatic, similar effects of the forecast selected can be seen in Figures 5, 8, 10, and 12 for the emissions results.

1.2.16.4 In response to a question from a Member, the meeting noted that noise results were presented in the form of an impact, i.e. population exposure, compared to the other results that were presented in inventory form. A discussion on whether future emissions results should be presented as impacts will be discussed under Agenda Item 5 based on the recommendations of the Impacts ad hoc group and the future work requirements.

1.2.16.5 The meeting also noted that the population exposed to aircraft noise results for the future scenarios did not consider the effects of population growth in the vicinity of airports. After consultation with WG2, MODTF determined that changes in population in the areas surrounding airports is typically an airport-specific issue and that while desirable to have, data at this level of granularity is not currently available at a global scale.

1.2.16.6 The meeting accepted the global environmental trends assessments and confirmed that it had addressed the request from the 36th Session of the Assembly.

1.2.17 **Recommendation**

1.2.17.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 1/1 – Acceptance of the global environmental trends assessments**
>
> The global environmental trends assessments by MODTF are accepted by CAEP and should be used to inform the 37th Session of the Assembly.

1.3 INDEPENDENT EXPERT LED REVIEWS FOR TECHNOLOGIES

1.3.1.1 In support of the work programme agreed at CAEP/6, a panel of Independent Experts (IEs) was tasked with leading a review of technologies for the control of oxides of nitrogen (NO_x) culminating in the IEs recommendations for medium (10 year) and long term (20 year) goals for NO_x control. This review was conducted in March 2006 in London and a final report was presented during CAEP/7. Since the results of the review were well received at CAEP/7, the committee agreed that this NO_x review was to be treated as a reference for similar efforts for other areas viz., Noise, Fuel Burn, and Operations were requested. During CAEP/8, reviews for NO_x, Noise, and Operations have been held and their respective Independent Expert Panels have produced reports documenting the results including medium and long term goals. For fuel burn reduction technologies, a workshop was held which enabled its Independent Expert Panel to assess fuel burn technology advances to date and formulate preliminary views on prospects for future fuel burn technologies. The state of progress on these four initiatives (goals for NO_x, Noise, Fuel Burn, and Operations) and related items was presented by the respective Independent Expert Panels and industry to CAEP/8 and is summarized below.

1.3.2 NO_x Reduction Technologies (Task E.04.2 and E.04.3)

1.3.2.1 The first Independent Expert (IE) Review of aircraft NO_x control technologies, held in March 2006, led to the setting of 10 year Mid Term (MT) and 20 year Long Term (LT) NO_x Technology Goals:

a) 2016, medium term (MT), CAEP/6 levels – 45%, ±2.5% (of CAEP/6) at a PR of 30

b) 2026, long term (LT), CAEP/6 levels – 60%, ±5% (of CAEP/6) at a PR of 30

1.3.2.2 These goals were accepted by CAEP/7 and the complete report was published electronically on the ICAO website as Doc 9887.

1.3.2.3 CAEP/7 requested a second Review by IEs to assess progress towards meeting the goals and to update, where necessary, the previous work. The IEs held this review in London during March 2009. The IE Panel consisted of four of the six original members: one from France, two from the UK, and one from the US.

1.3.2.4 The report presented to CAEP/8 summarized further significant reductions in NO_x emitted by aircraft engines fitted with the latest combustors and of predicted reductions resulting from combustors still in development. At the time of the Review no engines had yet met the Goals set at the first review as defined by having reached Technology Readiness Level 8 (TRL8). However, considerable data was presented for advanced conventional Rich burn, quick Quench, Lean burn (RQL) combustors indicating that, as expected from the first Review, evolutionary developments continue to appear likely to meet the MT Goal, though with a considerable challenge remaining. Data was also presented for new and more revolutionary staged Direct Lean Injection (DLI) combustors which showed dramatic reductions in NO_x production, again in line with the expectations of the 2006 Review. The lead engine family to be fitted with a DLI combustor, the GE GEnX, was shown as being developed over a remarkably wide range of Overall Pressure Ratio (OPR). The lowest OPR development of this engine showed promise of meeting even the LT Goal, whereas, at the highest OPR it would have difficulty meeting even the MT Goal. This wide spread of NO_x performance raised questions about how such families of engines might be handled within a Goals setting. Despite the considerable progress made since the first Review, the IEs decided not to recommend a change either to the Goals or the definition of their achievement. The key reasoning for retaining the present Goals was to avoid hasty, and possibly ill-conceived, changes to what were intended to be mid and long term targets, and in this regard to give time for the performance of the new staged DLI combustors to be proven in service and for their applicability to smaller engines to be investigated. It was also concluded that DLI- style combustors are likely to be essential for meeting the LT Goal especially for large, high OPR engines. Furthermore, if it transpires that for small low OPR engines the trade-offs associated with fitting advanced RQL and DLI combustors in fact precludes their use in such engines then the characteristic slope of the Goals may well require significant change. For current RQL combustors nothing in this Review was found to disturb the currently accepted relationship between the amount of NO_x produced during the prescribed certification Landing and Take-Off Cycle (LTO) as compared with that produced at the Cruise condition. However, concern was again expressed about uncertainties for this relationship as a result of both the significantly different behaviour of staged DLI combustors as well as of potential new engine architectures such as open rotor engines.

1.3.2.5 The IEP Chair noted in particular:

a) if anything the evidence of NO_x impact is more compelling for both Climate Change and Air Quality;

b) the conclusion of the IEs not to change the Goals at this Review; and

c) their recommendation for a further review in about three years time with a larger panel of independent experts.

1.3.2.6 The IEP Chair also recommended the inclusion of certain work items to the CAEP work programme. These include a) better quantifying the direct and indirect (e.g. through PM formation) impact of NO_x surface air quality and climate change, b) applicability of new technologies to the whole OPR range of engines, c) issue of cruise NO_x, and d) harmonization with other Goals activities. Further discussion on these items was postponed for Agenda Item 5.

1.3.2.7 The meeting took note of the information presented by ICCAIA summarizing recent progress in development and application of low emissions combustor technology as presented during the second LTTG NO_x Goals Update Review meeting held in London during March 2009. The aspects covered included the technology development process, emissions of recently certificated engines, technology development programmes relevant to products introduced in the 10-year time frame, and research programmes relevant to the longer term.

1.3.3 **Discussion and Conclusions**

1.3.3.1 The meeting congratulated the Independent Expert Panel on its effort and noted the conclusions and recommendations of their report. The meeting also expressed its appreciation of the efforts of the industry in making this review a success. The meeting approved the report for future use within CAEP and agreed that the report should be made publicly available on the same basis (published on the ICAO public website in English only) as the original report (ICAO Doc 9887). It should further be made clear that this report was the work of independent experts and not an ICAO report. Also, it was agreed that all the presentations relating to the LTTG review would be made available on the ICAO public website.

1.3.3.2 The Secretary requested clarification on timeline harmonization and whether there was any proposal to align the medium and long term horizons with other such exercises for noise and CO_2. The IEP Chair noted that the current review keeps the original dates but, depending on when the next review is held, it is anticipated that any new goals exercise would likely be for medium and long term goals in 2020 and 2030, respectively. The Secretary highlighted that harmonization of the timeline and other aspects with other independent expert led reviews would be desirable.

1.3.3.3 The Chair supported by a member encouraged CAEP members to provide resources and experts to existing and future IE Panels to ensure the success of the process and to avoid undue burden on IEP members.

1.3.4 **Recommendation**

1.3.4.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 1/2 – Publication of "Report of the Independent Experts on NO_x Reduction Technologies Second Review and the Associated Medium and Long Term Goals"

That the report of the independent experts be published by ICAO as soon as possible.

1.3.5 **Noise Reduction Technologies (Tasks N.27 and N.29)**

1.3.5.1 As noted in the introduction to this section, CAEP/7 requested that an Independent Expert Panel (IEP) be formed to review the status of aircraft noise reduction technology and the prospects for aircraft noise reduction in the Mid-Term (Year 2018) and in the Long-Term (Year 2028). Subsequently, experts from Canada, France, USA, Russia, Japan and UK were nominated to form this panel.

1.3.5.2 The Noise Technology Independent Expert Panel (IEP) attended the Noise Technology Workshop as Observers, held in conjunction with the CAEP Steering Group Meeting in Seattle, WA, USA, on 26 September 2008. Following the Noise Technology Workshop, a Noise Technology IEP Review was held in Seattle, from 29 September to 1 October 2008. Presentations were given by various Industry members of ICCAIA as well as member States' research establishments reporting the progress of noise reduction technology research programmes in the EU, USA, Canada, Russia and Japan.

1.3.5.3 In subsequent meetings and telecons, the Panel, after reviewing with WG1 and obtaining consensus, agreed to evaluate four classes or categories of aircraft for future noise reduction goals, viz., Regional Jets (RJ), Small-to-Medium Range Twin Aircraft (SMR2), Long Range Two-Engine Aircraft (LR2), and Long Range Four-Engine Aircraft (LR4).

1.3.5.4 The IEP Chair described that the task of assessing the impacts of various component noise reduction technology concepts on total aircraft system noise was extremely difficult and complex, and that the IER material presented was insufficiently detailed to adequately assess the noise reduction potential of the technology concepts on total aircraft system noise reduction. The Panel therefore requested that industry members carry out additional "system benefit" studies, utilizing Panel-defined noise reduction concept packages or combinations, subsequently called "Pilot Studies." Aircraft manufacturer members of the planning committee graciously provided these Pilot Study results for the

SMR2 aircraft category, over a period of several months. These results, along with past NASA AST Program studies (documented in NASA TM-2005-212144, "Evaluation of AST Program Noise Reduction Benefits") and Panel analysis of the CAEP Best Practices Database information, provided the Panel with the information needed to develop noise reduction goal recommendations.

1.3.5.5 The Panel spent a considerable amount of time analyzing various data sources and technology presentation material to ensure that the Panel Goal recommendations are consistent from one aircraft category to another, and that they are consistent with the project aircraft Best Practices Database noise levels. In addition, the Panel developed a rational model for estimating the uncertainty associated with the Panel Noise Level Goals.

1.3.5.6 The IEP identified two contributors to aircraft system source noise reduction, viz., cycle improvements related to BPR increase and component noise reduction technologies. Noise Reduction Goals for the four categories of aircraft were developed by the Panel, as a result of intensive study of the available review material, Best Practices Database information, Pilot Study results, and results from the recently published NASA Advanced Subsonic Transport Noise Reduction System Assessment Studies. The Goals are given in terms of cumulative noise in Effective Perceived Noise Level, relative to the ICAO Annex 16, Chapter 4 limits. These Goals are summarized below:

Table 13: Mid-Term and Long-Term Noise Goals (Cumulative EPNL re: Chapter 4 Limits, @TRL8)

Aircraft Category	**Mid-Term (2018)**	**Long-Term (2028)**
Regional Jet	13.0	20.0
Small-Med. Range Twin	21.0	23.5
Long-Range Twin	22.0[12]	24.5
Long-Range Quad	21.0	23.5

1.3.5.7 The Chair of IEP noted that the uncertainty in the Panel Goal noise reduction estimates has been quantified and is available in the detailed report along with a detailed documentation of the Independent Expert Panel activities, processes, analyses, conclusions and recommendations.

1.3.5.8 It was further noted that the Noise Goal recommendations in the report are based on the best available information provided to the Panel on the benefits of noise reduction technologies and potential future vehicle configurations. The Panel utilized specific noise reduction technology benefits that can be realistically implemented in the mid-term and long-term timeframes, and implemented a process for projecting TRL6 technology to TRL8 readiness, using a percent realization factor. However, the marketplace will determine which technologies are actually implemented in future aircraft designs, and will depend on factors well beyond the scope of this Panel study. Hence there are likely to be significant variations in new aircraft noise levels within an aircraft category that may either exceed or fall short of the projections.

1.3.5.9 The IEP Chair noted in particular the need for CAEP/8 to consider establishing a work item on assessment of noise benefit realization factor for future noise goal forecasts.

1.3.5.10 The work of IEP was closely coordinated with Technology Task Group within WG1. WG1 provided its recommendations on related issues not included in the Independent Experts Panel's

[12] The goal was updated to 20.5 by the Independent Expert Panel after the CAEP/8 meeting.

remit such as Goals Update and Progress Evaluation as well as documented the lessons learned in view of developing a harmonized Technology Goals Process for CAEP.

1.3.5.11 The aspects relating to goals update and progress assessment processes were highlighted and CAEP was requested to consider the need for future work aimed at clarification of uncertainties and realization factor, with the objective of addressing this issue at a conceptual level consistent for all goals. Furthermore, it was recommended that other issues associated with harmonization of technology goals processes (baseline dates, considered aircraft categories, goals format) be considered. Some issues concerning the exploitation of the noise technology goals both within and outside CAEP, including publication of IEP reports, were also brought forward. It was agreed that these aspects will form part of the discussions on CAEP future work.

1.3.6 **Discussion and Conclusions**

1.3.6.1 The meeting congratulated the Independent Expert Panel on its accomplishments concerning the Noise Technology Goal Recommendations effort and noted the conclusions and recommendations of their report. The meeting approved the report for future use within CAEP and agreed that the report should be made publicly available on the same basis as the NO_x report. Also, it was agreed that all the presentations relating to the noise technology review would be made available on the ICAO public website.

1.3.6.2 One member noted that some goals across aircraft categories seem conservative whereas others may be looked at as ambitious. The IEP Chair commented that the goals are with respect to the baselines derived from the best practice database and therefore a function of the current technology being used and a realization factor for future technologies. The Secretary identified the difference in the use of realization factor from TRL6 to TRL8 (medium term) used by the noise IEP compared to NO_x which used only TRL8. The concept and magnitude of realization factor should be explored in CAEP's future work.

1.3.6.3 The Chair requested the NO_x and noise IEs to coordinate and present to the meeting the implications and proposals for future work including an expansion on the concept of realization factors.

1.3.6.4 Several members agreed with the IEP proposal of holding noise reviews every other CAEP cycle with the proviso that any significant change may necessitate review of this frequency. It was further noted that one such topic to be addressed in future work would be the impact of open rotor technologies on the noise environment.

1.3.6.5 The meeting agreed that any presentations from the workshop will be vetted for sensitive material before being made available on the ICAO public website. It also agreed that the material of the report be similarly vetted before publication.

1.3.7 **Recommendation**

1.3.7.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 1/3 – Publication of "Report of the Independent Experts on Noise Reduction Technologies Review and the Associated Medium and Long Term Goals"**
>
> That the report of the independent experts be published by ICAO as soon as possible.

1.3.8 **Fuel Burn Reduction Technologies (Task E.04.1 and E.04.3)**

1.3.8.1 CAEP/7 requested advice from Independent Experts (IEs) on the prospects for reduced aviation fuel burn from technology advances over ten and twenty years based on the effects of "major technologies" on fuel burn/efficiency, as well as combinations of improvements from both aircraft and engines, including best possible integration. The IEs have to focus their analyses only on technologies, and not on operations or new types of fuels, while quantifying interdependencies as much as possible.

1.3.8.2 The CAEP/8 Steering Group in 2008 (SG2008) agreed on a two stage process comprising a) an industry led Workshop in early 2009, and b) a formal IE led Review early in the CAEP/9 cycle, and a final report to the first meeting of the CAEP/9 Steering Group (SG2010).

1.3.8.3 ICCAIA conducted a Fuel Burn Reduction Technology Workshop from 25 to 26 March 2009 in London. The workshop was an opportunity for industry and research organizations to share with the CAEP Steering Group the status of the technologies for fuel burn reduction explored by airframe and engine manufacturers and government researchers. Independent Experts attended the Workshop for familiarization with the materials presented. The presentations were summarized by ICCAIA and the complete presentations are available on the ICAO secured website, on the CAEP, Workshops, ICCAIA Fuel Burn Reduction Technology Workshop menu.

1.3.8.4 The Chair of IEP described the activities undertaken by the panel so far. A survey of 12 airlines and 2 leasing companies, also stakeholders in ordering new aircraft, has been conducted. It was noted that some responses reflected an expected evolutionary business-as-usual type of development. Nevertheless a wish for more fuel-efficient aircraft versions seems to be overtaking the traditional emphasis of keeping maximum commonality across fleets. The airlines are concerned about likely increased costs which new technology might involve. There is also concern regarding possible changes in infrastructure (e.g., major alterations at airports to accommodate different aircraft configurations) which might be required by new technologies that potentially offer more significant fuel efficiency improvements, because of concerns about costs and time required to implement the infrastructure changes. Many airlines, however, are eager to obtain new technology as soon as possible.

1.3.8.5 The IEs believe that four classes should be considered: Regional Jets, Single Aisle (101-210 passengers), Twin Aisle-1 (211-400 passengers) and Twin Aisle-2 (>400 passengers). The IEs felt that their work needed to be informed by some modelling efforts, either by the IEs, or work commissioned by the IEs. It was agreed to limit the scope of effort to what seems achievable in the allotted timescale and comprises the major impacts. Consequently the IEs will consider in depth the Single Aisle and the Twin Aisle-1 (211-400 pax) categories, since these are responsible for the overwhelming majority of the current fuel burn.

1.3.8.6 The IEs collated a summary table of the technology targets that were presented at the ICCAIA Technology Workshop in March 2009 and from the International Air Transport Association (IATA) Technology Roadmap for Environmentally Sustainable Aviation (TERESA) project and to a lesser extent other studies. This table is reproduced below:

Table 14: Independent Experts summary table of technology targets.

Technologies						Generic aircraft N.3	Generic aircraft N.4	Generic aircraft N.5	Generic aircraft N.	Generic aircraft N.	Generic aircraft N.
					Ref aircraft	B737/A320	B737/A320	B737/A320	B787/A350	B787/A350	B787/A350
	Probability				Category	2	2	2	3	3	3
	High				Range	3000	3000	3000	6000	6000	6000
	Medium				Scenario	2	2	3	2	2	3
	Low				Scope	2020	2030	2030	2020	2030	2030
				Availability in 2020	Availability in 2030						
Propulsion	Improovement in propulsion efficency					15%	20%	30% / 37%	8.5%	14%	31%
			SFC			0.51	0.48	0.4%	0.50	0.48	0.4%
						BPR=10	BPR=13	BPR=50	BPR=12	BPR=13	BPR=50
	Increase of propulsive efficiency		improovement of propulsive efficiency			12%	16%	28%	5%	8%	22%
		Light weight technologies									
		Variable nozzle									
		Active laminar flow control									
		Supression of reverse		2%				2%			2%
	Increase of OPR										
		Increase of thermal efficiency				3.5%	4.7%	2%	3%	4%	2%
			Water injection	3%				3%			3%
	Reduction of aéro. Losses										
	Reduction of cooling losses										
			Inter cooler	2%				2%		2%	2%
	New cycles										
		Geared Fan		1%	2%						
		Variable cycle (2nd gen)		?%							
		Open rotor		10%							
		Buried, boundary layer ingesting installation concepts		4%							
Airframe aérodynamic			Aérodynamic Improovement			7%	14%	20%	7%	14%	20%
	Natural aérodynamic										
			Improoved aero tools	3%	5%	3%	5%	5%	3%	5%	5%
			Spiroid wingtips	2%		2%	2%	2%	2%	2%	2%
	Laminar flow										
			Riblets or coating	2%	5%						
			Active laminar flow	5%	10%		5%	10%		5%	10%
	Morphing geometrie										
			Variable camber with new control surfaces	2%		2%	3%		2%	3%	
			Morphing materials and wing		5%			5%			5%
Airframe weight			Weight improovement			10%	15%	23%	10%	15%	23%
	Wings and empenages										
		New materials		4%	8%	4%	6%	8%	4%	6%	8%
		Optimisation of geometrie									
		Reduction of loads	Active smart wing	7%		3%	5%	7%	3%	5%	7%
		Active Stability			5%			5%			5%
	Cabin and fuselage										
		New materials				2%	3%	4%	2%	3%	4%
	Systems										
		Landing gear in Ti				1%	1%	1%	1%	1%	1%
		More electric aircraft (MEA)					1%	1%		1%	1%
New airframe configuration											
		Blended wing body			10%						10%
		Truss-Based Wing									
		Cruise Efficient Short Take-Off and Landing									
Operation on ground											
		Electric landing-gear drive			3%		3%	3%		3%	3%
		Fuel cells									
Rough Total possible gain						25 - 30%	40 - 45%	55 - 60%	20 - 25%	40%	60%

1.3.8.7 The simplified presentation of this information has proved beneficial. However, there were many gaps within the table and it was agreed that these fields should be completed, if possible.

These estimates will inform the modelling to be carried out on different aircraft types to inform the goal setting effort.

1.3.8.8 The IEs decided that particularly for the 20 year goals they should consider a range of technology scenarios. These will be related to technology and not directly to economic, societal and political situations. It is recognised that these factors will apply some of the pressure to incorporate new technologies, but there is considerable uncertainty as to the effect. Rather than predict the precise level of future environmental pressures and future fuel prices, the chosen scenarios are intended to represent technology responses to increasing pressure for improvement. The three Technology Scenarios to be considered by the IEs are TS1: Evolutionary technologies, low to moderate pressures for improvement; TS2: Aggressive evolutionary technology development and insertion, high pressure for improvement; and TS3: Revolutionary technologies, doing things differently, and severe pressure for improvement.

1.3.8.9 The IEs have agreed to hold the Review in the week beginning 24 May 2010 as proposed by ICCAIA, whilst believing this to be very late. The intention of the IEs is for the real work of the Review to have been carried out in advance of the meeting. Hence two days would suffice for the formal Review, with the remainder of the week used by the IEs to prepare their report. This will only be possible if ICCAIA is able to deliver the results of their studies well in advance of the 24 May 2010 Review.

1.3.8.10 The IEs agreed from the start that they must do some modelling of aircraft to explore independently the effect on fuel burn of technology and configuration changes. Members of the IE team are in a strong position to do some of this modelling (e.g., Stanford University). Additionally, where possible collaboration with other groups would be desirable and it is hoped to involve researchers at the Georgia Institute of Technology and the German Aerospace Centre (DLR) (which are linked to the IATA-TERESA project noted above), as well as the U.S. National Aeronautics and Space Administration (NASA). The IEs would also welcome input from other organisations and are particularly keen to use the knowledge and expertise of the International Coalition for Sustainable Aviation (ICSA), a structured network of Non-Governmental Organisations (NGO) concerned with the impact of aviation on the environment.

1.3.8.11 It is important to limit the tasks and the cases for which analysis is performed because resources, including time, are severely limited. For this reason, the IEs have decided to concentrate their modelling on two types which together burn most of the fuel, viz., single aisle aircraft (A320, B737 type) and twin aisle 1 (211-400 passengers). Of particular relevance to the 20-year goals, the IEs will consider three technology scenarios (TS), viz., TS1: Evolutionary technologies with low to moderate pressure for improvement, TS2: Aggressive evolutionary technology development and insertion with high pressure for improvement, and TS3: Revolutionary technologies, doing things differently, with severe pressure for improvement.

1.3.8.12 Currently discussions are taking place to see if the ICCAIA Technology Reference Aircraft can be used as the basis for this modelling. Some overlap in cases modelled by or on behalf of the IEs with those performed by industry is essential to build confidence in the IE work, but it is envisaged that the availability of separate IE methods will allow a wider range of radical cases to be examined in TS2 and TS3.

1.3.8.13 The IEP noted that work on the appropriate metric to use in setting CO_2 Standards is under consideration by WG3 and the IEs recognize the need for coordination with these other ongoing activities.

1.3.8.14 The IEs believe that they are capable of delivering a useful report for the first meeting of the CAEP/9 Steering Group in late autumn 2010 on the basis of a successful formal Review during the week beginning 24 May 2010. This will only be possible if most of the promised exchange of information and most of the modelling calculations have been achieved well before that formal Review meeting. The basic form of the report must be agreed prior to that date with the Review meeting primarily used to discuss the findings as well as to refine the report and its conclusions. Further work after this point may be required.

1.3.9 **Discussion and Conclusions**

1.3.9.1 The meeting noted the progress to date, although it has not been as significant as IEs would have liked, and expressed its gratitude to the Independent Expert Panel for its work. However, there was considerable concern on the perceived lack of coordination between the industry and independent experts. The urgency of this work was highlighted and it was stressed that the dates of review (24 to 28 May 2010) be held fixed and the preparatory work for the review be accelerated by the industry.

1.3.9.2 The meeting also discussed making the review presentations available online. Because of proprietary concerns, it was decided not to make these available for now. However, after the review has taken place, this issue should be revisited by the Steering Group.

1.3.9.3 There was agreement to continuation of the development of fuel burn technology goals as outlined in the IEP report while noting that discussions on details are on-going. It was further noted that the ongoing work based on fuel burn metrics (kg fuel/ATK) should continue to be coordinated with other activities on metrics e.g. on potential CO_2 technology standards.

1.3.9.4 In answer to questions from the meeting, an observer clarified that manufacturers aspire to lower the noise of aircraft with open rotor engines compared to aircraft with current turbofan engines but only future development of technologies will answer the question definitively.

1.3.9.5 An observer highlighted the importance of prioritization if we are to accomplish tasks such as the IE review of fuel burn reduction technologies while making progress on a CO_2 Standard. A member asked for early completion of the IEs work to avoid further conflict in resources. The meeting noted that the tasks of fuel burn reduction goals and CO_2 Standards should feed each other instead of compete for resources.

1.3.10 **Recommendation**

1.3.10.1 In light of the foregoing discussion, the meeting developed the following recommendation:

Recommendation 1/4 – Review of Fuel Burn Reduction technologies by a Panel of Independent Experts to establish medium and long term technology goals for fuel burn reduction

That the review be held no later than 24 to 28 May 2010 and its report be presented to the first Steering Group meeting in preparation for CAEP/9.

1.3.11 **Environmental Improvements from Operational Initiatives (Task O.08)**

1.3.11.1 The Independent Expert Operational Goals Group (IEOGG) was tasked, based on the independent expert (IE) process, to examine and make recommendations for noise, NO_x and fuel burn with respect to air traffic operational goals in the medium term (10 years) and the long term (20 years). Using the baseline year of 2006 being assessed by MODTF, the medium term was defined as 2016 and the long term as 2026.

1.3.11.2 The IEOGG Chair explained that due to the expertise required for this assessment, the group was comprised of experts provided by a broad range of domains, including: airport operators, Air Navigation Service Providers (ANSP), national authorities, international organisations, industry, airline trade associations, and academia. Due to the time available to complete the task, the group did not conduct any new research and applied a top down approach based on readily available information. A bottom up approach was then used to validate the results.

Noise Goal

1.3.11.3 Since the greatest concentration of aircraft noise is typically very close to the airport, the procedures intended to either concentrate or disperse aircraft noise are by necessity airport specific. As a result, the group found that there is no global plan for the application of a specific noise abatement technique and that the local application of noise mitigation measures is mature. As a result, the group did not feel that it would be appropriate to recommend an operational goal related to noise.

NO_x Goal

1.3.11.4 Aircraft NO_x emissions depend on a number of parameters, including the engine exhaust temperature. Due to the non-linear relationship of NO_x emissions to fuel consumption, the group felt that the evaluation of changes in NO_x emissions resulting from operational changes would be better assessed through modelling. The IEOGG chair noted that aircraft operations are currently not driven by NO_x performance requirements.

Fuel Burn Goal (Expressed as Operational Efficiency)

1.3.11.5 The IEOGG Chair summarized environmental goals for future operations proposed by the group in accordance with the requirements of CAEP. The goals provide an initial range estimate of operational efficiency assuming that the present aggressive operational improvement initiatives are implemented in the timescales proposed (i.e. the ICAO Global Air Navigation Plan including the SESAR and NextGen programmes).

1.3.11.6 The topic of operational efficiency is the subject of numerous regional assessments with a number of studies that are currently underway. These studies typically reflect a single region or are presented from the perspective of a single stakeholder. The knowledge base used by the group for determining the goals was therefore incomplete and is continuously evolving. The goals presented are intended to be taken as an initial snap-shot estimate based on current readily available information.

1.3.11.7 The IEOGG Chair noted that while the work on the group focused on operational improvement related goals, it was suggested by the CAEP Steering Group that other factors should be considered such as those related to operator commercial decisions (e.g. aircraft selection, yield management parameters, etc.). However, the IEOGG felt that it would unlikely for such factors to be considered in a future goals review.

1.3.11.8 Because of the gaps and uncertainties in the available information the IEOGG has presented its regional goals in the form of a range. It is essential that the proposed Operational Goals are not taken or used out of context and that they are always associated with the discussion and limitations contained in this report. When reproducing or referring to the goals the user must ensure that the context, discussion and limitations are clearly expressed and that the risk of misinterpretation is minimised.

1.3.11.9 The overall ATM system Global Operational Efficiency Goal was presented as follows:

a) The global civil ATM system shall achieve an average of 95% operational efficiency by 2026 subject to the following caveats:

   1) This goal should not be applied uniformly to Regions or States;

   2) This is to be achieved subject to first maintaining high levels of safety whilst accommodating anticipated levels of growth in movement numbers in the same period;

   3) This operations relevant goal does not cover air transport system efficiency factors that depend on airspace user commercial decisions (e.g. aircraft selection, yield management parameters, etc.);

   4) This operational efficiency goal can be used to indicate fuel and carbon dioxide reductions provided fuel type and standards remain the same as in 2008. The goal does not indicate changes in emissions that do not have a linear relationship to Fuel use (such as NO_x); and

   5) This assumes the timely achievement of planned air and ground infrastructure and operational improvements, together with the supporting funding, institutional and political enablers.

1.3.11.10 The following key limitations were noted by the IEOGG:

a) IEOGG was effectively given two months (including the holiday season) to prepare the operational goals, which should therefore be taken as an initial estimate.

b) The relationship between operational efficiency and fuel efficiency / CO_2 / NO_x was not fully explored as this is an expertise area of the modelling community. However, to the extent that enhanced ATM capabilities reduce trajectory inefficiencies, NO_x emissions should also be reduced.

c) The methodologies for calculating 'efficiency' in the source material used by the IEOGG to formulate the goals were not always completely clear. In many cases the group inferred that the approach was to sum separately assessed inefficiencies to give a picture of total inefficiency which was then subtracted from 100 to give efficiency. This includes considering factors such as predictability and 4-D business trajectories which may increase the benefit pool as well as unavoidable safe separation requirements which could lead to a decrease in the benefit pool.

d) Complete and robust information on inefficiencies for certain ICAO Regions was not available to the authors of the supporting reports used by IEOGG. These regions may in fact have more uncertainty than what is implied in the report.

e) In the case that this process be repeated in the next CAEP round, a full appraisal of the IE process as applied by the Technology IE reviews will be conducted, lessons learned and applied in the new IE Operations review. It is anticipated that more time and resources will be required in order to fully respect the process.

f) Several efficiency related factors such as wind optimisation of trajectory and reduced fuel upload from improved predictability were not covered by the reference reports used by IEOGG. These effects could not be estimated by the IEOGG because of lack of data. With more time available to conduct the exercise, it is possible that some of these data could be established to better inform the final report.

g) Although noise is addressed in this report, it is anticipated that this aspect would be further developed in any new report produced for example in the next CAEP round.

1.3.11.11 The IEOGG agreed that 100% fuel efficiency would not be fully attainable because of a range of factors such as safe separation requirements, noise routes and unavoidable perturbations (e.g. from unplanned military activities or unpredicted weather events).

1.3.11.12 The IEOGG anticipates that ATM operational environmental goals provided herein can be used for:

a) informing modelling and forecasting activities;

b) informing policy, mandates and regulations;

c) to frame challenging but realistic expectations within the ATM community, by the public and to inform goal setting stringency from other improvements;

d) to provide a benchmark against which to monitor operational improvement delivery (requires a monitoring and reporting process); and

e) to inform the development of environmental KPIs.

1.3.12 Discussion and Conclusions

1.3.12.1 The meeting, acknowledging the time constraints and the fact that this was the first review of its kind, congratulated the IEOGG on its accomplishments concerning the assessment of environmental improvements from global operational initiatives. There was broad and enthusiastic support by CAEP members and observers for the work delivered by the IEOGG as a first step and for its continued development in the future. The conclusions and recommendations of their report were noted as a good first step.

1.3.12.2 A member agreed with the IEOGG Chair that the results presented in the report are preliminary and more work is needed to polish and finalize the report before adoption and publishing. Several members and observers agreed with the limitations of the analysis as described by the IEOGG chair and in some cases, expanded on the limitations. A member recalled the issues raised at the 2009 Salvador Steering Group and agreement to address them, and reiterated that the work of the IEOGG would not be complete until these issues were addressed. There was agreement by the meeting that this effort needs to be continued and strengthened while ensuring that synergies with other similar tasks at global and regional levels are exploited.

1.3.12.3 A member highlighted the importance of operations assessment and how it may incorporate environmental trade-offs related to issues such as farther-out noise. Another member noted that farther-out noise should not be equated to operational goals and the two issues need to be considered on their own merits for inclusion in future work.

1.3.12.4 Some members brought to the attention of the meeting issues such as weather and capacity (hold on ground vs. delays in the air) that directly impact any efficiency assessments. The IEOGG chair expressed the panel's willingness to consider these issues while highlighting the associated complexities.

1.3.12.5 The meeting agreed that in light of all the reviews' presentations, the next round of technology goals review should establish goals for 2020 and 2030 with a baseline of 2010. The frequency of reviews would be a function of the technology and the progress made in prior years. It was also agreed that any scoping exercise for any new IE Operational Goals task, be coordinated with rapporteurs of noise and emissions working groups with a view toward generating a global set of harmonized goals.

1.3.12.6 The Secretary expressed the need to clearly define working methods including membership in the IEOGG and timelines for this review as well as harmonization with other CAEP independent expert led reviews. She noted that the IEOGG composition would necessarily be different because the efficiency issues depend to a large extent on implementation rather than development of new technologies. The IEOGG chair was requested by the meeting to outline next steps, in coordination with IEP and other experts, for this task under the future work agenda item.

1.3.13 **Follow-on Work from the Impacts Workshop (Task MOD.04)**

1.3.13.1 During CAEP/7, CAEP Members and Observers agreed that a scientific workshop would be organized to assess the state of knowledge and gaps in understanding and estimating noise, air quality and climate impacts of aviation. Additionally, the workshop would critically examine the key issues towards comprehensive evaluation of environmental impacts of aviation.

1.3.13.2 The Workshop on "Assessing Current Scientific Knowledge, Uncertainties and Gaps Quantifying Climate Change, Noise and Air Quality Aviation Impacts" was held in Montréal, from 29 to 31 October 2007. The Workshop Co-Chairs presented the final report of the Workshop to the 2nd meeting of the CAEP Steering Group in Seattle, Washington (September 2008).

1.3.13.3 The CAEP Steering Group established an ad-hoc group in order to develop a strategy for taking forward the recommendations of the Impacts Workshop report. This strategy was presented to the 3rd meeting of the CAEP Steering Group in Salvador, Brazil.

1.3.13.4 The CAEP Steering Group asked for further consideration on approaches to making additional expertise available to CAEP in order to fully benefit from the recommendations of the Workshop, while recognising limited resources.

1.3.13.5 The co-Chairs of the Workshop presented a proposal for the formation of an Impacts Task Force (ITF) to CAEP/8 to advance the implementation of the recommendations of the Impacts Workshop in the near term (CAEP/9 cycle) and assess the status of the research supporting longer term (CAEP/10 and beyond) recommendations. However, the underlying research to support the recommendations would generally be best delivered through national and regional research programmes. Organising the research in a global group with sufficient expertise across all recommendation would be too resource intensive. Relying on national and regional research programmes to support the ITF would permit groupings of experts to work through the technical detail in a timely and effectively manner and the ITF to focus on the application of the research to CAEP specific tasks.

1.3.13.6 To minimize resources required, the ITF could be viewed as a first step focused on high priority areas, for example climate impacts and particulate matter emissions and their air quality impacts. ITF membership could initially comprise primarily experts in climate impacts and health and exposure impacts of aviation emissions. Expertise on interdependencies and economics (which would include some noise capabilities) could be added, depending on the CAEP/9 Work Programme needs. The Impacts Workshop scientific participants would be the initial, but not the only source, of potential ITF members. In relevant subject areas, existing Research Focal Points and Scientific Focal Points (RFPs/SFPs) could also support the ITF as appropriate.

1.3.13.7 Composition of the ITF together with its funding by individual States and terms of reference would need to be established once the CAEP/9 Work programme is agreed to. Ultimately, the size of the ITF should be balanced between small enough to facilitate progress, and large enough to represent a range of scientific views.

1.3.13.8 The ITF would be largely 'virtual' to facilitate participation and minimize required resources. Members could be invited to attend specific meetings of CAEP Working Groups, MODTF or FESG to provide specific advice as needed.

1.3.13.9 The process for posing specific questions to the ITF could be based on the process adopted by CAEP for querying the existing RFPs and SFPs. That process has ensured that questions are well-formed aimed at aiding the CAEP work programme and transmitted in a transparent way.

1.3.13.10 The ITF would function as a source of information from its own expertise but also as a channel of communication between CAEP and expertise elsewhere on impacts related subjects. Information should flow both ways: ITF would take questions from CAEP to the research community as well as provide answers and other relevant information to CAEP. ITF would in particular (but not only) look to other UN bodies like the World Health Organization (WHO) and the Intergovernmental Panel on Climate Change (IPCC) for impacts knowledge. National and regional research programmes could also inform the ITF.

1.3.13.11 To facilitate the work of the ITF, the ITF should have co-chairs who would aid interface with relevant CAEP Working Groups, MODTF and FESG as needed and monitor progress. The Impacts Workshop co-chairs could initially serve as the ITF Co-Chairs to facilitate progress. To develop the Terms of Reference of the ITF, the Impacts Workshop co-chairs could convene a small workshop comprising the six climate, air quality and noise co-chairs of the Impacts Workshop subject areas and the

Rapporteurs of the Working Groups, MODTF and FESG to discuss and review what the Impacts Workshop outputs were, what the CAEP work programme is, and what the responses of CAEP Working Groups 1 and 3, MODTF and FESG have been thus far, in terms of implementation plans.

1.3.13.12 The co-chairs also highlighted the linkage of ITF potential work with the HLM recommendations.

1.3.14 **Discussion and Conclusions**

1.3.14.1 A member proposed that the group be called an Impacts Experts Group to avoid confusion with a task force that is created to complete a specific task. There was general agreement with this proposal. Several members and observers offered resources to the group.

1.3.14.2 CAEP further encouraged Working Groups, MODTF and FESG to consider the feasibility of implementing the recommendations from the Impacts Workshop in light of the ICAO Programme of Action as endorsed by the High-level Meeting and the Council, the priority areas of the CAEP/9 work programme and available resources.

1.3.14.3 It was thought important that terms of reference be clearly presented to CAEP members and observers. The co-chairs undertook to present these draft TORs to the first Steering Group meeting after CAEP/8, basing the process for posing scientific questions to ITF on the process currently used for queries to the RFPs and SFPs. The meeting agreed that a small workshop may be convened to define the terms of reference of the ITF while ensuring that duplication of effort is minimized.

1.3.14.4 It was clarified by the Secretary that such a group would complement the work of the Secretariat and, resources allowing, could serve as a consultative body to the ICAO Secretariat. She highlighted that it would not represent ICAO in any UN body or other fora. Possible areas of work for this group could include issues such as non-CO_2 effects and the implications of a global climate change target to aviation.

1.3.14.5 The States were also encouraged to sponsor research to advance the scientific basis for those recommendations designated as requiring more research in the near term to enable implementation in the far term (CAEP/10 and beyond) and keep CAEP informed of the developments/research efforts.

1.3.14.6 An observer suggested that the Impacts Expert Group aim to meet alongside CAEP Working Group 3 meetings and involve Observer Organizations in their work.

General Considerations for Research and Technologies

1.3.14.7 The meeting noted the information submitted by US, Canada, UK, and EC on research programmes being undertaken in their respective States or regions. These programmes include PARTNER and OMEGA. Some of the projects related to alternative fuels and technology models were highlighted. ICCAIA reviewed the work already undertaken under CAEP auspices on technology readiness levels as they pertain to technology goals and Standards.

— — — — — — — —

Agenda Item 2: Review of technical proposals relating to aircraft engine emissions

2.1 REPORT OF WG3 – EMISSIONS TECHNICAL

2.1.1 General Technical Issues

2.1.1.1 The Rapporteurs of Working Group 3 presented the group's report. Most of the work items were examined within the three Task Groups (Characterisation of Emissions (CETG), Certification (CTG) and Long Term Technology Goals (LTTG)). Ad-hoc groups were formed to address very specific topics. The remaining items were retained under the direction of WG3 itself. Liaison with WG1, WG2, FESG, MODTF and SAE was carried out via focal points.

2.1.1.2 The group has been continuing its work to monitor and foster research to further characterise the air quality and global effects resulting from the current and future aircraft exhaust emissions, including aviation's contribution relative to other sources. As an input to the consideration of aviation's contribution relative to other sources, the established WG3 Science Focal Points and CAEP Local Air Quality Research Focal Point provided a tutorial and some conclusions on source apportionment, specifically under what circumstances the apportionment of impact by mass emitted from sources (AIME) is valid for assessment of climate and air quality impacts from aircraft emissions.

2.1.1.3 The WG3 also continued to monitor trends in aviation kerosene fuel composition and assess consequences for emissions. It noted that no changes are required to the ICAO test fuel specification at this time. However, in light of the information collected on global kerosene fuel specification and the ICAO emissions test fuel as well as the potential for a CO_2 Standard and the emergence of alternative fuels, it was highlighted that work should continue on fuels used in certification tests. The information provided by WG3 on fuel supply composition was complemented by studies on ultra-low-sulphur fuels by a member and an observer.

2.1.1.4 Working with other CAEP WGs and in support of MODTF analysis, WG3 developed databases and technical inputs to support the assessment of associated trade-offs in the CAEP/8 work programme. These inputs comprise of the following:

- technology responses to NO_x stringency options;
- assumptions on future technology improvements with respect to noise and emissions as input into MODTF for the ICAO Environmental Goals Assessment;
- a review of the current global fleet database (Campbell-Hill) and the associated aircraft noise and emissions characteristics;
- a Growth and Replacement Database, incorporating noise, NO_x and fuel burn data, for use in populating the generic FESG future fleet forecast with actual airframe-engines; and
- additional data on business jets and turboprops, accounting for the fact that available noise and emissions information was non-certificated data or simply unavailable.

2.1.2 One member and an observer presented the work on potential reductions in sulphur content in aviation fuels. These issues are being coordinated within States for possible update of fuel specification Standards outside of ICAO.

Discussion and Conclusions

2.1.2.1 One member agreed with the WG3 Co-Rapporteurs that resources are limited and WG3 especially may become overloaded with tasks. This was also discussed at the last Steering Group meeting where it was stressed that prioritization be done to address resource constraints. The member also mentioned that all efforts be made to keep abreast of technical work outside CAEP in order to avoid duplication of effort, but particularly for the area of alternative fuels.

2.1.2.2 The member also highlighted the importance of continuing the PM work which will also be discussed in section 2.4.

2.1.3 **Proposed Changes to Annex 16, Volume II**

2.1.3.1 The WG3 considered a number of proposals for the amendment of Annex 16, Volume II. Some of these proposals were a result of updates to SAE-E31 documentation.

2.1.3.2 For reflectometers' Standards, it was determined that there is no need to change or amend current wording in Annex 16. In order to harmonise Annex 16 Volume II with ARP 1179 rev. C on the use of filters, some guidance text for the ETM was proposed (provided in Appendix B to the report on this agenda item and discussed in section 2.1.3 related to ETM Volume II).

2.1.3.3 In reviewing Annex 16, Volume II, Appendix 3, Attachment A, the group found inconsistencies with SAE ARP 1256C on the operating temperatures of the Total Hydrocarbon Analyzer. SAE E-31 has been contacted and they have initiated work to revisit ARP 1256 and ARP 1179 with the aim to achieve a harmonized approach. This work will continue during CAEP/9 and no Annex 16 revisions are related to this work at this time. For the time, being guidance material has been developed for the ETM with respect to the HC analyser. Therefore, no change in language in Annex 16, Volume II is proposed.

2.1.3.4 An observer had requested a review of the Annex 16, Volume II humidity measurement requirements. Some initial work has been started but not yet finished. It is proposed to carry this work over to the CAEP/9 work programme.

2.1.3.5 The proposed changes to Annex 16, Volume II are summarized in the following section and the ETM is covered in section 2.1.3 – Development of Environmental Technical Manual (ETM) Volume II.

Equivalent Procedures

2.1.3.6 CAEP/7 requested WG3 to consider harmonisation of the wording "variations in procedures" within Annex 16, Volume II and "equivalent procedures" in the ETM. While there was no clear definition from the review of historical records, the group concluded that the term "variations in procedure" is effectively the same as "equivalent procedure" which is defined in the ETM. Therefore, the language has been made consistent and now refers to "equivalent procedure" throughout Annex 16, Volume II.

Other amendments to Annex 16 and ETM

2.1.3.7 The co-rapporteur of WG3 clarified to the group that any recommendation on a production cut-off Standard based on CAEP/6 NO_x Standard will need to be included in Annex 16, Volume II. In order to implement a potential CAEP/6 NO_x production cut-off Annex 16, Vol. II, Chapter 2, paragraph 2.3.2 (d) needs to be amended to cover for the ceasing "date of manufacture of the individual production engine" which is subject to CAEP/8 discussions and agreement. Various amendments are proposed to link the Annex 16 requirements on this issue with the associated guidance in the ETM (discussed in section 2.1.3 related to ETM Volume II).

2.1.3.8 In the same way, any potential increase in NO_x stringency that may be agreed at CAEP/8 will need to be included in Annex 16 Volume II. Paragraph *2.3.2 Regulatory levels* would be amended by a subparagraph. The structure of this paragraph is dependent on the agreed stringency option. However, it would be similar to subparagraph d) containing applicability dates and subsequent formulae.

Editorial Corrections

2.1.3.9 Further edits with regard to typographical errors and moving of paragraphs to more appropriate places were identified.

Discussion and Conclusions

2.1.3.10 The meeting agreed to the proposed amendments and recommended that these be incorporated as part of the Annex 16, Volume II amendments included in Appendix A to the report on this agenda item.

2.1.3.11 A member brought to the attention of the meeting an issue in the French version of Annex 16, Volume II. He further suggested that the term "production cut-off" be clarified so that it means "engine production cut-off". The meeting agreed to incorporate this clarification in Annex 16, Volume II as provided in Appendix A to this report. The meeting also agreed to his proposed French text for Annex 16, Volume II, Appendix B, page B-3, para 1.5:

> *1.5 Les Etats contractants reconnaîtront la validité des dérogations à une exigence de cessation de production de moteurs qui sont accordées…*

2.1.3.12 A member expressed concern on the provision that exemption from production cut-off "shall be reported by engine serial number and made available via an official public register". The WG3 representative explained that transparency in the process drove this requirement. One member clarified that process of granting exemption in her State involves issuing a notice in the Federal Register. Another member stressed the importance of transparency. The meeting agreed that having this information publicly available is desirable.

2.1.4 Development of Environmental Technical Manual (ETM) Volume II

2.1.4.1 A WG3 representative presented the work on the development of a second Volume of the *Environmental Technical Manual* (ETM) for emissions, consistent and compatible with the approach taken for noise (Volume I).

Date of manufacture (Chapters 1 and 2)

2.1.4.2 The current Annex 16, Volume II applicability requirements are related to the “date of manufacture of the first individual production engine”, while for NO_x production cut-off requirements the date of manufacture refers to “date of issue of the document attesting that the individual…..engine….conforms to the requirements of the type”. Explanatory information on this text and agreed interpretation has been incorporated into the ETM as provided in Appendix B to the report in this agenda item.

Applicability of Certification Requirements (Chapter 2)

2.1.4.3 Based on principles that take into account past and current certification practice, guidance has been developed on how to treat the changes in an engine design which have no or very little effect on emission levels. It also includes guidance on when new emissions levels would need to be determined, when a new certification test would be required, and whether the certification basis from the parent product would be retained or, due to substantial modifications, the latest Standard applied.

Process and criteria for NO_x production cut-off exemptions (Chapter 2)

2.1.4.4 Significant discussions on a potential CAEP/6 production cut-off requirement have taken place since SG2009 in order to harmonise the approach on a global basis. The agreed guidance on the process and evaluation criteria for applications associated with NO_x production cut-off exemptions has been prepared for the ETM.

Validation of emissions sampling rakes (Chapter 2)

2.1.4.5 ETM guidance has been agreed clarifying the Annex 16, Volume II provision that “the applicant shall provide evidence to the certificating authority, by means of a detailed traverse, that the proposed probe design and position does provide a representative sample for each prescribed power setting” requirement.

Status of supersonic engine emissions requirements (Chapter3)

2.1.4.6 WG3 has clarified their current position on this issue, which had previously been presented to CAEP/7, via the inclusion of text within the ETM.

Smoke emission evaluation (Appendix 2)

2.1.4.7 ETM guidance has been agreed specifically referring to the use of a specific filter as best practice.

Instrumentation and measurement techniques for gaseous emissions (Appendix 3)

2.1.4.8 ETM guidance has been agreed for Annex 16, Volume II, Appendix 3 on instrumentation and measurement techniques for gaseous emissions. This work included the need to clarify the post processing of measured emissions data taken during a certification test. In coordination with SAE E-31, the group has also begun to develop guidance associated with the Attachments to Annex 16, Volume II, Appendix 3 which contain the specifications for all gaseous emissions analysers.

Outstanding issues for CAEP/9

2.1.4.9 Several ongoing issues that have not been completed are expected to be carried over into the CAEP/9 work programme. These include evaluation of Optical Smoke Meters (OSM) for use in certification tests, and development of further guidance on Annex 16, Volume II, Appendix 3 Attachments.

Discussion and Conclusions

2.1.4.10 The meeting noted the group's efforts in completing the ETM Volume II. Recalling past discussions at CAEP/7 where it was agreed to delay publication of the emissions ETM in anticipation of a revised version of Volume I of the ETM, it was agreed that, assuming finalization of the noise ETM in Agenda Item 4, both volumes of the ETM can be recommended for publication now. The proposed emissions ETM is attached as Appendix B to report on this agenda item.

2.1.4.11 A member pointed out that even within "spare" and "new" engine categories, there may be some overlap on the definitions which may lead to double-counting. The WG3 representative explained that these categories have been defined rigorously in the ETM and no such issues are foreseen. The difference in "spare" and "new" is based on whether they increase the number of engines in operation or not. The intent of spare engines is not to increase the number of engines in operation.

2.1.4.12 Another member inquired into an effective cap per engine type (around 75) for exempted engines as described in the proposed text. The WG3 representative answered that this explains normal practice and is not a "hard" cap. He explained that it is the same case for the time limit of 4 years for new engines after the implementation date of production cut-off. Overall it is a guidance document and as such is provided to States for their use at their discretion. The cap and time limit does not impact the engines produced to maintain in-service fleets.

2.1.4.13 The Secretary noted that the exact title of the Environmental Technical Manual and its two volumes will need to take into account harmonization with other ICAO publications and editorial practice. The meeting requested the Secretariat to finalize the exact title during the publication process.

2.1.5 **Recommendation**

2.1.5.1 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 2/1 — Publication of Environmental Technical Manual, Volume II

That the Environmental Technical Manual, Volume II, contained in Appendix B to the report on this agenda item, be published as soon as possible.

2.2 CONSIDERATION OF CAEP/6 NO_X PRODUCTION CUT-OFF

2.2.1 Based on a decision by CAEP/7 and at WG3's request FESG conducted an economic assessment of introducing a production cut-off date for the engines to which the NO_x Standards developed at CAEP/6 applied. The FESG analysis estimated the non-recurring costs of making affected engines compliant with a production cut-off to the CAEP/6 NO_x Standard. This effect was estimated to be approximately US$100 million in 2008 US dollars. In the event that the decision is made to bring the affected engines into compliance, recurring costs would arise. A broad analysis of recurring costs, based on the analysis of the NO_x stringency options performed for CAEP/6 suggests that these may be higher by factors of between 4 and 9, depending on whether loss of resale value is included. In the case where airlines would not be able to acquire additional engines for spares, these costs could be significant, with serious implications for the continued operation and resale value of the affected aircraft. In these circumstances a 9 fold factor giving an overall cost of US$ 900 million provides a minimum estimate of these costs. At the same time, the environmental benefits will remain small.

2.2.2 A member recalled that the CAEP/2 emission Standards incorporated a later production cut-off to ensure that appropriate emission control technologies were incorporated into all new engine designs and in-production engines by a certain date. Subsequently, CAEP/4 and CAEP/6 NO_x Standards were adopted without such a production cut-off.

2.2.3 The member recalled that the Steering Group in Salvador stated that "although there was no objection in principle from the [Steering Group] members for a CAEP/6 NO_x Standards production cut-off, there were some outstanding issues. CAEP SG agreed to address appropriately the issues related to exemptions and timing for the earliest implementation to allow for recommending to the ICAO Council at CAEP/8 the adoption of such a cut-off." Subsequently, the ETM Ad-hoc group within WG3 submitted an updated version of the ETM on the process and criteria for the exemptions to the NO_x production cut-off requirements. The approval of these exemption provisions via revisions to Annex 16, Volume II and guidance material in the ETM Volume II is expected as a result of CAEP/8.

2.2.4 The member invited CAEP/8 to agree that a production cut-off for the CAEP/6 NO_x emission Standards and the associated exemption provisions developed in the revised ETM and Annex 16, Volume II should be adopted, and then implemented on the earliest practical ICAO effective date. Ultimately, a CAEP/6 production cut-off provides certainty that non-compliant engines will eventually no longer be produced – but with the flexibility of exemptions allowing for time adjustments to lessen economic impacts. A production cut-off takes full advantage of the CAEP/6 NO_x Standards environmental benefits, ensures no backsliding, and communicates to the public the aviation sector's commitment to improving its environmental performance.

2.2.5 An observer presented a proposed method to show compliance with the CAEP/6 Standard before the imposition of production cut-off for NO_x Standard. For the most recent production cut off in 2000, certificating authorities accepted data and analysis that had been submitted and approved in accordance with previous amendments of ICAO Annex, 16 Volume II as evidence of compliance with the latest Standard. However, the criteria for demonstration of compliance should be more clearly described in Annex 16, Volume II.

2.2.6 In order to minimize administrative costs and avoid delays in demonstrating compliance with requirements for continued production, use of existing approved certification data and analysis should be allowed to demonstrate compliance with the CAEP/6 Standard, even if the data and analysis were obtained under a previous amendment of the procedures described in the Annex. Publication of explicit advice on the applicability of existing certification test data and analysis, either in the Annex or the ETM, would be helpful to manufacturers and certificating authorities. The observer proposed to add a paragraph to the ETM Volume II where guidance is provided to the relevant ICAO Annex 16 provisions.

2.2.7 The meeting agreed to the addition of this proposed text to the section in ICAO Environmental Technical Manual (ETM), Volume II where guidance is provided to 2.1.1.1 of ICAO Annex 16. The agreed text is incorporated in Appendix B to the report under this agenda item.

2.2.8 In another presentation, the same observer proposed that in order to allow sufficient time for member States that issue type certificates for aviation to fully adopt the CAEP/6 Production Cut-off Standards, and for manufacturers to demonstrate compliance, where necessary, the implementation date should be set for 31 December 2012.

2.2.9 **Discussion and Conclusions**

2.2.9.1 One member expressed his concern with a potential CAEP/6 production cut-off when, in his view, FESG had identified that market forces had already responded to the Standard with very few exceptions and that it was not cost effective. Effective exemption provisions for in-service aircraft are also necessary to ensure that low-volume high-cost markets, especially in remote areas, are not impacted. He also expressed the hope that acceptance of this proposal does not introduce a trend towards conservatism in the development of future Standards.

2.2.9.2 Several members pointed out that this production cut-off should be understood as only applying to CAEP/6 Standard and not for any future Standards. The meeting agreed that any future proposal for production cut-offs would need to be considered on a case-by-case basis.

2.2.9.3 There was general support for the production cut-off proposal and also the applicability date of 31 December 2012. In light of this general support, the meeting recommended that a production cut-off for CAEP/6 NO_x Standards be applied by 31 December 2012 and the associated exemption provisions developed in the revised ETM and Annex 16, Volume II be updated.

2.2.9.4 The meeting recommended that the provisions for a production cut-off based on CAEP/6 NO_x Standard be incorporated as part of the Annex 16, Volume II amendments as indicated in Appendix A to the report on this agenda item.

2.3 CONSIDERATION OF NEW NO_X STRINGENCY OPTIONS

2.3.1 The FESG and MODTF Co-Rapporteurs presented an overview of the assessment of the environmental benefits and economic costs of stringency scenarios to reduce emissions of nitrogen oxides (NO_x) relative to the ICAO CAEP/6 Standard. They briefly discussed the models, databases, methods and assumptions used by MODTF and FESG to conduct the environmental benefit and economic cost assessments.

2.3.2 As part of the NO_x stringency assessment framework, WG3 provided 10 scenarios for modelling, as shown in the following Table 1.

Table 1. NO_x Stringency Scenarios

NOx Stringency Scenario	Small Engines [26.7 kN / 89 kN Foo][1,2]	Large Engines	
		OPR[3]>30	Slope[4]
1	-5% / -5%	-5%	2
2	-10% / -10%	-10%	2.2
3	-10% / -10%	-10%	2
4	-5% / -15%	-15%	2.2
5	-15% / -15%	-15%	2.2
6	-5% / -15%	-15%	2
7	-15% / -15%	-15%	2
8	-10% / -20%	-20%	2.2
9	-15% / -20%	-20%	2.2
10	-20% / -20%	-20%	2.2

2.3.3 The 10 stringency scenarios were analyzed for each of 3 future years, 2016, 2026 and 2036. The assessment framework also called for two stringency introduction dates, 31 December 2012 and 31 December 2016.

2.3.4 The emissions reduction results from the MODTF assessment and the FESG assessment of the cost impact were presented, as follows, along with a discussion on environmental trade-offs.

Table 2 - Cost Results

NOx Stringency Scenarios	Low Cost Estimate ($M) 3% discount, 2016, LRV[5]	High Cost Estimate ($M) 3% discount, 2016, LRV
1 - 5	$ 1,922	$ 2,500
6 - 7	$ 6,412	$ 9,470
8 - 10	$ 10,878	$ 21,507

2.3.5 Finally the cost-effectiveness results were presented as costs per tonne of NO_x reduction during the ICAO Landing Take Off (LTO) cycle, including the ranking of the stringency scenarios.

[1] Foo – Thrust rating. For engine emissions purposes, the maximum power/thrust available for takeoff under normal operating conditions at ISA (International Standard Atmosphere) sea level static conditions without the use of water injection as approved by the certificating authority. Thrust is expressed in kilonewtons (kN).
[2] Incremental stringency options defined for small engines with thrust ratings (Foo) comprised between 26.7 kN and 89 kN.
[3] OPR – Overall Engine Pressure Ratio. The engine pressure ratio is defined as the ratio of the mean total pressure at the last compressor discharge plane of the compressor to the mean total pressure at the compressor entry plane, when the engine is developing its takeoff thrust rating (in ISA sea-level static conditions).
[4] Slope of the line of the NOx stringency options at engine pressure ratio (PR) greater than 30.
[5] LRV – Loss in Resale Value.

Table 3 – Cost-Effectiveness Ranking, Large Engines

Ranking	Stringency Reference	NOx Reduction % / Slope of Dp/Foo
1	NS01, NS02, NS03, NS04, NS05	-5% / 2.0, -10% / 2.2, -10% / 2.0, -15% / 2.2
2	NS06, NS07	-15% / 2.0
3	NS08, NS09, NS10	-20% / 2.2

Table 4 – Cost-Effectiveness Ranking, Small Engines

Ranking	Stringency Reference	NOx Reduction %
1	NS01, NS04, NS06	-5% / -5%, -5% / -15%
2	NS08	-10% / -20%
3	NS02, NS03	-10% / -10%
4	NS10	-20% / -20%
5	NS09	-15% / -20%
6	NS05, NS07	-15% / -15%

2.3.6 **Cost Results**

2.3.6.1 Costs were estimated for each stringency scenario for the two implementation dates for small and large engine categories separately, with a range of values for a number of key assumptions, including non-recurring costs, fuel burn penalty, fuel price, loss of resale value (LRV) and a variety of discount rates. As summarized in Table 2, total costs for small and large engines combined are broadly similar for stringency scenarios 1 through 5, but for scenarios 6 through 10 costs increase steeply, driven by non-recurring costs for engines driven by need of a major technology response. While efforts were made to comprehensively quantify all costs, some costs were not included. For example, increased industry operational costs in scenarios involving higher fuel burn were partially itemized to include fuel costs and costs associated with loss in payload for payload limited flights.

2.3.7 **Environmental Trade-offs**

2.3.7.1 An important part of the NO_x stringency assessment is the consideration of environmental trade-offs between the various NO_x stringency scenarios, fuel burn, and noise. WG3 recommended a fuel burn penalty range of between 0% and 0.5% for engine families requiring a major (MS3) modification. MODTF included the maximum of 0.5% penalty in its modelling and calculations. Figures 8 and 9 provide the maximum potential fuel burn penalty for the full-flight case, presented in terms of total fuel and percent, respectively. These are MODTF consensus results calculated with AEDT and confirmed by other CAEP approved models. In accordance with WG3 recommendations for the stringency scenarios assessed, the MS3 fuel burn penalty only applies to large engines and only for some engines in scenarios 6 through 10. The maximum potential annual fuel burn penalty ranges from about 28,000 metric tonnes to 1.1 Mt (1.1×10^6 metric tonnes), or from 0.01% to 0.19% relative to the baseline no stringency case. This translated into additional annual CO_2 emissions of between 88,000 metric tonnes and 3.5 Mt. In accordance with WG3 recommendations the minimum fuel burn penalty is zero.

2.3.7.2 WG1 recommended a noise penalty range of between 0 decibel (dB) and 0.5 dB per certification point for 10% of engines requiring a major (MS3) modification, i.e. 10% of all engines. As with fuel burn, the MS3 noise penalty only applies to large engines and only for scenarios 6 through 10.

The effect of the MS3 noise penalty on the 55, 60 and 65 DNL[6] contour area expressed as a percentage change was in the worst case less than 0.12%. Based on these findings, MODTF concluded that the analysis indicates there **is no noise trade-off associated with any of** the CAEP/8 NO_x stringency scenarios. This conclusion has been verified at the global, regional and airport levels.

2.3.8 Cost-effectiveness Results

2.3.8.1 The cost-effectiveness results are dominated by large engines, which account for approximately 99% of the benefits. Scenarios 1 through 5 are the most cost effective, all providing relatively low cost per tonne of NO_x reduced. For scenarios 6 and 7, cost per tonne of NO_x reduced increased by a factor of 3 to 4, using a 3% discount rate. Scenarios 8, 9 and 10 result in a further doubling of cost per tonne of NO_x reduced. Cost-effectiveness rankings for large and small engines are shown in Tables 3 and 4, respectively. Although the analysis concentrates on NO_x reduction up to 3,000 ft, stringencies also have an effect on climb/cruise NO_x emissions. If these were taken into account, the total reduction achieved would increase by an approximate factor of 7 to 8, and the costs per tonne would diminish accordingly.

2.3.8.2 The early implementation date of 2012 gives overall lower values for the costs per tonne of NO_x reduced. This is enabled by an extra four years of NO_x reduction compared to 2016 implementation, coupled with roughly the same costs for both implementation dates. This implies that an early implementation year would be more cost effective. However, in the approach used, it is assumed that the non-recurring costs for the technology responses start four years in advance of implementation (from 2009). This may mean that in practice a somewhat later date than 2012 is more obvious, particularly for those scenarios involving MS3 modifications. The CAEP/6 decision made in 2004 with an implementation date of 2008 would be consistent with a CAEP/8 implementation date of 2014.

2.3.8.3 One member presented a proposal for NO_x stringency basing it on the analysis carried out by FESG and MODTF. The member stated that in order to make greater progress in reducing aviation's contribution to air pollution and to move meaningfully towards the long term technology goals, CAEP should consider adopting the most stringent NO_x Standard at CAEP/8, consistent with its principles for Standard-setting. The member's recommendations were based on analysis done within their State by using outputs from the APMT economics and impacts models. Based upon the FESG analysis and its own qualitative analysis of costs and benefits as provided to the meeting using APMT, the need for continuous air quality improvements, continued technology research and development evidenced during NO_x emissions reduction technology reviews for goal-setting, conservative estimates of additional environmental impacts that are still being matured, and additional information being provided on cost/benefit, the NO_x stringency scenario 6 for large and small engines (-15% and slope 2.0 for large engines and -5% / -15% for small engines) with a December 31, 2012 implementation date should be considered for adoption at CAEP/8. Alternatively, stemming solely from FESG's cost effectiveness results and the continued need for air quality improvements, at least the NO_x stringency scenario 4 for large and small engines (-15% and slope of 2.2 for large engines and -5% / -15% for small engines) with a 31 December 2012 implementation date should be considered for adoption.

2.3.8.4 Elaborating on the proposal, the member proposed that a slope of 2.0 be maintained for further stringency in recognition of likely future combustor technology development to meet mid- and long-term CAEP NO_x emissions reduction technology goals, and to foster engine and combustor technology development that considers the balance between fuel efficiency improvements and NO_x

[6] DNL – Day-Night Noise Level.

emissions reduction particularly for engines with pressure ratios greater than 35 to 40. Changing the slope to 2.2 would be an unnecessary relaxation of the slope that could potentially compromise this balance.

2.3.8.5 In summary, the proposal was for CAEP/8 to agree that NO_x stringency scenario 6 (-15% and slope of 2 for large engines and -5% / -15% for small engines) should be adopted, based on the discussion above and the need for air quality improvements including knowledge related to airport-local effects, cruise emissions influence on air quality, and future background concentration changes, as well as detailed APMT impacts calculations for cost/benefit. However, if CAEP/8 wishes, at least the NO_x stringency scenario 4 (-15% and slope of 2.2 for large engines and -5% / -15% for small engines) should be adopted, based on the need for air quality improvement and FESG's cost effectiveness results. Furthermore, it was proposed that the implementation date of 31 December 2012 should be adopted at CAEP/8 for both large and small engines applicability, regardless of stringency scenario.

2.3.8.6 A member introduced some data on recent analysis done on aviation emissions inventory in her country. The member further pointed out that analysis performed in her State showed that NO_x stringency scenario 1 through 7 have a similar impact on manufacturers, engine types, and engine orders. The NO_x stringency scenarios 8, 9, and 10 (-20% and slope 2.2 for large engines) impact many more engine types and orders compared to the other scenarios. The meeting noted the information shared by the member.

2.3.8.7 Two observers presented their position that, upon review of the data and analyses produced in the CAEP/8 process, adoption of new NO_x certification Standards (colloquially referred to as "stringency" Standards) for both large and small engines is warranted under the CAEP Terms of Reference. They stated that of the NO_x stringency scenarios analyzed by CAEP for large engines, the data and analyses best support adoption of FESG Scenario 2, a 10% increased stringency with a slope of 2.2. Scenario 4 (15% stringency increase at slope 2.2) would be less cost effective because it would require more extensive technology response and thus pose the risk that manufacturers would be unable to accomplish that development in time to meet any future production cut-off date. They noted that FESG and MODTF did not consider an intermediate scenario between a 10% and 15% stringency increase. As a result, there are no detailed analyses to support selecting such an intermediate stringency. Nevertheless, an intermediate stringency increase at slope 2.2 could potentially be the appropriate increase based on the CAEP Terms of Reference. The observers believed that the FESG data support adoption of a 5% increased stringency for small engines at the low end of the thrust range (26.7kN). Assuming that the selected stringency is Scenario 2, 10% at 2.2 slope (or in any event less than 15% with slope of 2.2), the analysis favours an effective date of year-end 2012, but in practice, this date might not provide enough time to respond to the new requirements. They proposed that a slightly later implementation date of year-end 2013 should be considered with a new Standard for large engines at -12% with a slope of 2.2 and for small engines at 5% (at 26.7 kN thrust).

2.3.8.8 Another observer highlighted the need for a new NO_x stringency. He expressed support for the NO_x Stringency Scenario NS7, (-15%/-15%, -15%/Slope 2.0) with an implementation date of 31 December 2012. Explaining his reasoning, he stated that Scenarios NS8-10 (2012 implementation) are calculated to provide a 9.7% reduction in NO_x below 3000 ft. For these options, however, the potential cost for manufacturers wishing to modify their in-production engine families could be significant. Scenarios NS6 and NS7 are predicted to provide more modest reductions of 7.3% in NO_x (in 2036) with considerably less cost for engine modifications. Scenarios NS1 to NS3, with engine NO_x reductions of only 5-10%, will provide less environmental benefit (<6% total NO_x reduction in 2036), albeit for less cost than other scenarios.

2.3.8.9 It was observed that new technology engines are typically at least 15% below CAEP/6 Standards, and that ICAO Standards should strive to reflect the achievements of the best technology. Scenarios NS4 and NS5 (with the steeper slope of 2.2 for OPR>30) include engine NO_x improvements of up to 15%, but provide less ambitious Standards for very large engines (i.e., the very engines responsible for the most NO_x emissions). When comparing NS6 and NS7, the only distinction is the Standards for the Small Engine families (26.7<Foo<89 kN and OPR<30 – typically regional and business jets 99 seats or less), with reductions of -5% and -15%, respectively. The observer preferred NS7 because it treats small and large engine manufacturers more equitably and yields additional benefits of 300 t of NO_x reduction per annum in 2036. It was further noted that the emissions from Large Engines dominate those of Small Engine families. Thus the overall reductions calculated for NS6 and NS7 are virtually identical. However, at many smaller airports the Large Engine families do not dominate aircraft NO_x emissions inventories; therefore these airports will not see the benefit of Large Engine family NO_x reduction. While on a global scale, the difference between NS6 and NS7 is very small, at a local level for smaller airports, the NS7 improvement in the NO_x performance of smaller aircraft will be very important.

2.3.8.10 The observer supported an implementation date of 31 December 2012. He stated that the Panel of Independent Experts had noted the compelling need for action. The economic analysis shows a modest additional cost for engine modifications whereas the earlier engine modifications will result in a NO_x saving of 8.5 kt per year.

2.3.9 **Discussion and Conclusions**

2.3.9.1 The meeting congratulated the FESG and MODTF and all their participants for putting together this detailed package. There was general appreciation for the amount of work that was put in this analysis not just by FESG and MODTF but also by groups within CAEP such as WG3 and from outside CAEP from the modelling communities.

2.3.9.2 The environmental trade-offs were done in terms of emissions inventories. Some members hoped that analysis in terms of impacts on passenger demand could be part of the future work. Some members expressed that there was a need to account for costs that might be potentially transferred to airlines and passengers which is currently not a part of the analytical procedure. The FESG Co-Rapporteurs clarified that CAEP had requested only a cost impact analysis to the industry and not to the passengers and public in general. The Chair agreed with this position that the mandate given to the FESG and MODTF was from this committee and if there is identified a need to expand the analysis to impacts (cost to passengers or in terms of impacts), it should be made part of future work.

2.3.9.3 A member highlighted the trade-offs between aviation growth and its environmental responsibility. A member queried whether CIS built aircraft were part of the analysis and the Chair indicated that no CIS built aircraft were included due to lack of data.

2.3.9.4 A member queried that whether the impact on developing countries was a part of the study. The FESG co-rapporteur clarified that the analysis was done by engine families and not for how the engines were operated in different regions of the world. The member further remarked that current economic crisis might add more complications to the analysis.

2.3.9.5 Another member emphasized the relevance of the current economic crisis and the passing of any industry costs to the passengers. The FESG and MODTF accomplished the task they were given but now the need to study this aspect has increased. Therefore, this issue needs to be made a part of future assessments. He suggested that a decision made now could be revisited if additional analysis was done that showed adverse economic impact.

2.3.9.6 Another member, taking this point further, stated that the current economic crisis may necessitate that the implementation date should be end 2016.

2.3.9.7 The Chair clarified that revisiting a decision on stringency Standards is neither practical nor possible. The Chair stressed that such an approach would not be procedural. Once a Standard has been agreed, it goes through a number of steps for formal global approval. Therefore, once a decision is reached by CAEP, it is not feasible to change it during the subsequent steps.

2.3.9.8 A member mentioned that their modelling capabilities do allow calculating consumer impact. Such an analysis, although it cannot be formally introduced in this CAEP meeting, was done and did not show a significant impact on consumers or the overall economy.

2.3.9.9 Regarding the issue of the impact on passengers, a member clarified that FESG did address the impact on demand which is directly related to consumer impact, and the conclusion was that the effect was minimal. Although this aspect was not the focus of extensive analysis, it was addressed.

2.3.9.10 A member expressed concern on basing a new Standard on MS3 technology and that such action may not allow time for market forces to adjust in an effective way.

2.3.9.11 A member pointed out that this is a certification Standard and therefore any engines complying with this Standard will not go into service until at least 2017 or later. Thus, any consumer impact would be smoothed out and should be minimal. Another member highlighted the interdependencies within the environmental parameters and between environmental and economic issues and that they should be incorporated in any future analyses. The meeting agreed that all interdependencies should be taken into account in future analysis.

2.3.9.12 An observer asked whether the sales volume of current aircraft/engines was taken into account for future fleets. The MODTF rapporteur clarified that future fleet composition was driven by assumption of equal manufacturer split. The same observer commented that the emissions benefit of current engines which perform much better than any future Standards are not being taken into account adequately. Another observer commented that if environmental benefit of such engines is taken into account then the cost of such engines would also have to be accounted for.

2.3.9.13 An observer clarified that he was proposing a slope of 2 above OPR45 because of the fact that increasing slope to 2.2 may result in worse than the CAEP/6 Standard at higher OPRs, which is not the intent.

2.3.9.14 During discussions on the level of a new NO_x stringency, some members and observers preferred NS6 or NS7, whereas other members and observers considered NS2-NS4 more appropriate.

2.3.9.15 An observer speaking on behalf of a group of countries stated that they preferred NS7 scenario which differs from NS6 mainly in application to small engines. The reason for the preference was stated to be that small engines have not had any stringency increase over the last few years. It was further proposed that an implementation date of end of 2013 be adopted. The observer recommended to the meeting that CAEP not consider any production cut-off based on this Standard before 2016 and any potential cut-off should not be implemented before 2018. Several members supported this position.

2.3.9.16 An observer stated that cost effectiveness should be the criterion for making any stringency decision. His preference was for NS7 with an implementation date of end 2012.

2.3.9.17 Regarding the small engine issue, a member said that a decision should be driven by the availability of technology and not by how long the same Standards have been in place. Also looking at the study data on large engines, the NS4 scenario seems the best for a future Standard.

2.3.9.18 Two members, in the spirit of compromise, proposed adoption of NS5 with an implementation date of end 2012 or end 2013.

2.3.9.19 A member expressed his preference for NS6 with an implementation date of end 2013 in order to give industry time to adapt to the change.

2.3.9.20 After extensive discussions among the CAEP members, the Chair was pleased to inform the CAEP plenary that a consensus was reached about the question of which new NO_x stringency level should be applicable to aircraft engines in the future. After a thorough discussion of the options, members converged to the adoption of a new Standard based upon option 6 (i.e. NS6).

2.3.9.21 Although some members were of the view that a less stringent Standard according to option 4 would be more appropriate to adopt, after further discussions during which there was consensus that any new stringency evaluation in the future should be undertaken by carrying out a more thorough assessment of economic impacts especially on airlines and passengers and that there will be no production cut-off considered based upon a CAEP/8 stringency Standard before 2018, a consensus on option 6 was reached.

2.3.9.22 The meeting came to the following decision:

a) Adoption of a new CAEP/8 stringency according to option 6, which means reduction of small engines -5% and -15% with respect to the CAEP/6 Standard, and for large engines, reduction of -15% with respect to the same Standard with the slope of 2.

b) This stringency should be implemented by 31 December 2013, and it should be clearly noted that no production cut-off before year end 2018 will be taken into consideration or should be applied before this date.

2.3.9.23 An observer pointed out that some in-production engines, although not required to comply with this Standard, requiring MS3 changes may not be able to comply with this Standard by 2013. Another observer sought clarification on the consideration or application of future production cut-off before year end 2018. The Chair clarified that there should be no implementation of a production cut-off before year end 2018.

2.3.9.24 The meeting recommended that the provisions for a CAEP/8 NO_x Standard as outlined in 2.3.9.22a) be incorporated as part of the Annex 16, Volume II amendments as indicated in Appendix A to the report on this agenda item.

2.3.10 Recommendation

2.3.10.1 In light of the foregoing discussions, as well as the prior discussions on amendments to Annex 16, Volume II and NO_x production cut-off, the meeting developed the following recommendation:

RSPP | **Recommendation 2/2 — Amendments to Annex 16, Volume II – Aircraft Engine Emissions**

That Annex 16, Volume II be amended as indicated in Appendix A to the report on this agenda item.

2.4 STATUS OF PARTICULATE MATTER SCIENCE AND STANDARDS

2.4.1 A member reported that Particulate Matter (PM) related to aircraft engine exhaust can be divided into two broad categories: non-volatile PM and volatile PM. The science is more advanced on non-volatile PM and it is certain that reducing non-volatile PM from aircraft engines will reduce health impacts due to aircraft emissions and will also help to mitigate aviation climate impacts.

2.4.2 Recently, the U.S. Federal Aviation Administration (FAA), U.S. Environmental Protection Agency (EPA), and European Aviation Safety Agency (EASA) have agreed to pursue the definition of a non-volatile PM emissions certification requirement. However, it is to be noted that EPA plans to continue investigating volatile PM emissions.

2.4.3 In March 2009, the *SAE-International* E-31 committee published the Aerospace Information Report (AIR) 6037 on measurement methods for non-volatile PM emissions from aircraft engines. The FAA, EPA, and EASA have requested that final Aerospace Recommended Practices (ARP) that focuses on metrics and the quantification of non-volatile PM mass and number as metrics be published by the end of 2011. Outstanding research to address technical questions would have therefore to be completed in the latter part of 2010. Among the most pressing research is the need for reference instrument calibration Standards, as well as a robust sampling and measurement methodology.

2.4.4 The development of the ARP by the SAE E-31 committee is a critical task that still needs to be accomplished before proceeding to developing the non-volatile PM emissions certification requirement. The timing of the work on a PM emissions certification requirement by WG3 will therefore occur late in the three year CAEP/9 cycle, although ongoing dialogue and coordination should continue to occur between participants of the SAE E-31 committee and CAEP.

2.4.5 The CAEP Air Quality Research Focal Points and WG3 Science Focal Points reported on two important areas of interest, viz., the latest understanding of aviation PM impacts on both ambient air quality and climate change, and the assessment of the availability of necessary data elements required for environmental impact studies of such effects. An update on policy-relevant scientific results related to these two areas was also provided.

2.4.6 **Discussion and Conclusions**

2.4.6.1 A member noted the importance of research on PM issues and suggested that it be made part of the future work. Several CAEP members and observers expressed support for this task.

2.4.6.2 The meeting agreed on considering this item as part of future work, focusing on non-volatile PM for now, with certification requirement targeted by CAEP/9 and a certification Standard to be established by CAEP/10. It was also noted that aspects of this work should be addressed in the Impacts Experts Group (discussed in section 1.3.13). The Chair noted that further discussions on prioritization may be held under the future work agenda item.

2.5 **AIRCRAFT CO_2 EMISSIONS**

2.5.1 **Fuel Efficiency Metrics**

2.5.1.1 During discussions on assessment of ICAO environmental goals, air traffic operational goals, and aircraft and engine technology goals, the question of metrics has been extensively debated. An ad hoc group was formed to address the task of defining simple metrics that can be applied to global commercial aviation activity, noting that one single metric might not be appropriate for the three different proposed uses.

2.5.1.2 For application to the CAEP/8 trends assessment of the ICAO environmental goals task, a metric named the Commercial Air System Fuel Efficiency (CASFE) metric was developed. The CASFE metric takes the familiar form of fuel consumed divided by sum of (payload x distance). However, it is important that the metric is not separated from its data sources, applicability and caveats.

2.5.1.3 While the CASFE metric is considered suitable for application to the CAEP/8 Environmental Goals trends analysis, further work on improvement of payload data and on further validation of the CASFE metric against actual airline data was suggested. It was also stated this metric is suitable for kerosene-like fuels only keeping in mind that this does not take into account life-cycle CO_2 costs of any potential alternative fuels.

2.5.1.4 Work on the air traffic operational goals and fuel burn reduction technology goals has not been completed within this CAEP cycle. As a result, fuel efficiency metrics applicable to these types of goals cannot be developed yet. However, for the air traffic operational goal input to CAEP/8, application of the CASFE metric was offered as an interim measure with the same caveats and issues as for the application of CASFE to the ICAO Environmental Goals trends assessment. Beyond CAEP/8, it was recommended that given the complex relationship between fuel efficiency and operational efficiency, consideration of a fuel efficiency metric applicable to future Operational Goals is not regarded as a separate task but is undertaken as part of the Goals process itself. This tasking should include the metric development and also the data and caveats to support it.

2.5.1.5 Similarly, it was recommended that the development of an appropriate fuel efficiency metric (and the data and caveats to support it) for application to the fuel burn reduction technology goals be included as part of the goals establishment process itself.

2.5.1.6 In addition to the three types of metrics mentioned above, the ad hoc group considered issues surrounding a metric accounting for alternative fuels as well as a fuel intensity metric that had been introduced in GIACC. It was noted that the task of identifying appropriate applications, data sources, and associated clarifications would need to be made part of future work.

2.5.1.7 An observer highlighted that the future work programme for CAEP should include the evaluation of an alternative efficiency metric appropriate for business aviation operations based on maximum payload instead of revenue payload. He explained that business aviation's main purposes are on demand and point to point transportation of people or goods and therefore the payload weight needs to be calculated differently.

2.5.2 **Discussion and Conclusions**

2.5.2.1 The meeting acknowledged the importance of selection of the right metric for a given use. It was highlighted that work should be continued with relevant bodies (e.g. CANSO) and independent experts panels and duplication of effort should be avoided. The meeting also noted the contribution of business aviation and its relatively small share of overall aviation emissions and that appropriate metrics should be used when calculating efficiencies.

2.5.2.2 The meeting agreed that development of fuel efficiency metrics should be continued within the ad-hoc group in coordination with relevant organizations and bodies.

2.5.3 **Recommendation**

2.5.3.1 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 2/3 — Fuel Efficiency and CO_2 Emissions Metrics

That the CASFE metric be established as the metric for assessment of ICAO environmental goals for global civil aviation and that work be continued on defining other appropriate metrics for operational and technology goals and Standards.

2.5.4 **Consideration of Aircraft CO_2 Emissions Standard**

2.5.4.1 As a result of a recommendation from GIACC/4 and the High-level Meeting, the ICAO Council decided to seek to develop a global CO_2 Standard for new aircraft types consistent with CAEP recommendations. As a result, CAEP and its technical working groups were requested to carry out a scoping analysis to help inform discussions on a potential CO_2 emission Standard at CAEP/8 and to help define a future work item within the CAEP/9 work programme.

2.5.4.2 The WG3 had performed a scoping analysis on a global CO_2 Standard for aircraft. Several members and observers have made important contributions in this regard and presented additional material to CAEP/8. The presentations by WG3 and other members and observers outlined a number of significant policy and technical questions and issues which should be considered and assessed in developing an aircraft based CO_2 emission Standard.

2.5.4.3 The WG3 recommended that a potential Standard in this area be referred as a "CO_2 Standard" based on "fuel efficiency" concepts within the certification requirement metric. In addition, the WG3 proposed the following definitions:

- Parameter – a measured or calculated quantity that describes a characteristic of an aircraft (e.g. Foo, MTOW, Optimum Cruise Speed)
- Metric – a certification unit consisting of one or more parameters (e.g. Dp/Foo)
- Procedures – specific certification procedures, including applicability requirements (e.g. Annex 16 Volume II, Chapter 2)
- Instrumentation and measurement methodology – technical measurement procedures (e.g. Annex 16 Volume II, Appendix 3)
- Certified level – approved for a specific product by a certification authority to demonstrate compliance with a regulatory level, as determined by the certification requirement
- Regulatory level – a limit which a certified level must meet (e.g. CAEP/6 NO_x)
- Certification requirement – the combination of metric, procedures, instrumentation and measurement methodology, and compliance requirements
- Standard – combination of a certification requirement and a regulatory level

2.5.4.4 The WG3 identified high level objectives of the overall Standard setting exercise in order to assess future proposals and, as far as practicable, to identify an optimum way forward:

- Provide an additional incentive to improve aircraft fuel efficiency and thus global fleet fuel burn performance
- Measure fuel burn performance and relevant capabilities (e.g. range, size, speed) across different aircraft types
- Ensure it is technically robust (now and future) with an acceptable level of accuracy
- Represent key aircraft design characteristics and environmental performance with respect to individual design philosophies (e.g. 2 / 3 spool engines or regional jet / narrow body / wide body aircraft types)
- Equity across products and manufacturers
- Permit flexibility in aircraft design to comply with requirement
- Minimise counterproductive incentives
- Minimise adverse interdependencies

- Base it on existing certified data

- Account for proprietary data protection concerns

- Not require an inappropriate level of resources on the part of National Airworthiness Authorities and ICCAIA to implement

- Be simple, transparent and easily understood by the general public

- Develop a standard as soon as reasonably practicable to ensure that ICAO maintains its leadership in addressing aviation emissions issues

2.5.4.5 The WG3 presented results of its scoping analysis for a Standard on Aircraft CO_2 emissions. Based on this scoping analysis, the WG3 concluded the following with respect to developing an aircraft CO_2 Standard:

- previous CAEP work related to this issue should be considered and, where appropriate re-examined, in order to benefit from past lessons learnt;

- consistent use of agreed terminology is essential in order to structure future discussions on this issue;

- proposals for an aircraft CO_2 Standard should be assessed against the high level objectives;

- the initial scope of any future work should focus on the sub-sonic jet aircraft category, which represents approx. 95%+ of global fuel use from commercial aviation, in order to improve the potential of agreeing on a CO_2 Standard during the CAEP/9 cycle;

- discussions on further focusing the scope of a Standard on a sub-category of the subsonic jet aircraft have identified two options for consideration in defining the future work item remit:

    - A MTOW threshold of ≥ 50,000 kg (110,231 lb);

    - A MTOW threshold of ≥ 32,500 kg (71,650 lb) and a maximum passenger seating capacity of ≥ 20 (freighter aircraft above 32,500kg would be included).

- the certification metric(s) is a critical aspect to any future CO_2 Standard which should, as far as practicable, meet key criteria (e.g. reflect fuel efficiency of an aircraft at a design and operational level, include parameters which characterise aircraft output, equitable, accuracy, limit interdependencies and easily understood), although associated timescales may result in compromises;

- the certification procedure will need to incorporate relevant aircraft design and performance characteristics;

- a kerosene-type fuel specification (e.g. Annex 16 Volume II Appendix 4) should be part of the certification requirement in order to remove any fuel burn performance variations resulting from variation in fuel properties;

- recognising that the SG2009 suggested that the initial focus should be on “new aircraft types”, and that they also agreed to defer further debate and discussions to WG3, the ad-hoc group concluded that all applicability options in terms of “new aircraft types”, “new production aircraft” or “in-service aircraft” should remain open for assessment at this point in time;

- in defining the applicability requirements, including the treatment of modified products, any associated standard and its effective date should be taken into account;

- the certification measurement methodology and required instrumentation is highly dependent on the discussions concerning the certification metric and procedure, and there may be a need to consult expert groups outside of CAEP;

- the current CAEP terms of reference and standard/goal setting approach may provide sufficient flexibility to be used to assess and agree on CO_2 Standards. Any different perspective may need to be considered by CAEP while taking into account the broader implications;

- to the degree possible, work on assessing regulatory level options should be done in parallel to the development of the certification requirement;

- further work should consider the advantages and disadvantages of all available approaches to manufacturer compliance, including those mentioned above and in further detail in CAEP/8-IP/21, when applied specifically to the aviation sector;

- timescales to develop a CO_2 Standard will be dependent on the priority placed on this issue and the provision of resources to take this work forward;

- establishing interim milestones with target completion dates will be necessary in order to manage the development of an aircraft CO_2 Standard;

- prioritisation of this issue in the future work programme may lead to delays in other work items; and

- the resources required to implement the certification requirement will be highly dependent on how it is designed and the associated workload for regulatory authorities and manufacturers.

2.5.4.6 A member presented her position on two points related to CO_2 Standard applicability, viz. a) to determine whether a CO_2 Standard should be applied to “new aircraft types”, “new production aircraft” and/or to “in-service aircraft” and b) to determine an aircraft size and/or seating capacity above which a CO_2 Standard should initially apply.

2.5.4.7 For the first point, the member stated a preference that the CO_2 Standard should apply to new in-production aircraft and not only to new aircraft types and recommended that CAEP not rule out applicability to new in-production aircraft. While realizing that to achieve near-term reductions, actions would have to be taken to improve in-service aircraft, the member expected that the ongoing ICAO process that follows the recommended programme of action from the GIACC and direction coming out of the High Level Meeting (HLM) should result in recommended additional actions that would address the CO_2 emissions contribution from in-service aircraft. Depending on the outcome of this ongoing process the member would consider the need for recommendations to CAEP/9 for appropriate work to be carried out to address in-service aircraft as part of the CAEP/10 work program.

2.5.4.8 For the second point, the member recommended the 32.5 tonnes MTOW option be pursued because the 50 tonne MTOW option does not achieve the targeted level of global fuel burn coverage and there is an expectation for growth in global and regional future fuel burn that should not be ignored. The member also recommended that the maximum seating capacity threshold of at least 20 passengers be dropped, for reasons of complexity and minimal environmental benefit. The member furthermore recommended that the CO_2 Standard's certification and reporting requirements should be applied to all commercial subsonic jet aircraft, including business jet aircraft, even though they may not be subject to any regulatory level when the CO_2 Standard is initially implemented. This would ensure an orderly process in the future, when these aircrafts' regulatory levels might be considered.

2.5.4.9 The member also expressed that in light of the criticality of this task, it is essential that the process be completed during the CAEP/9 cycle. She highlighted that this was feasible and in line with the need for ICAO leadership. She suggested a project plan which included four milestones before CAEP/9. Milestone 1, to be completed no later than May 2010, would be to agree on a Program Development Strategy. Milestone 2, to be completed prior to the 1st Steering Group Meeting would approve the Basic Program Construct including but not necessarily limited to areas such as Applicability, Scope, Certification Metric, and Fuel Specifications. Milestone 3, to be completed prior to the 2nd Steering Group Meeting, would conclude with a Basic Approach to Emission Standards, Stringency, and Timing. Elements for consideration would include the Regulatory Level and Form of the Standard, the Certification Procedure, the Timing of Initial and Subsequent Requirements, and Programmatic Structure Options and Flexibilities. Milestone 4, to be completed no later than October 2012, would analyse options identified earlier. This milestone would also include activities related to drafting of amendments to Annex 16 and the Environmental Technical Manual as required. The expectation would be that after these milestones and activities are complete and timelines are met, CAEP would have all the information needed to act on a CO_2 emission Standard during the CAEP/9 meeting in 2013.

2.5.4.10 The member recommended that the CAEP technical emissions working group (WG3) be assigned this task and be directed to establish a stand-alone task group (the "CO_2 Standards Task Group") with dedicated and empowered task group co-leaders (to ensure for contingencies) to lead the task to develop the CO_2 emission Standard. These task group co-leaders should come from a member state government or regulatory agency and the member volunteered an expert from its environmental protection agency to take one of the co-leader positions.

2.5.4.11 An observer recalled that WG3, in its scoping paper on a CO_2 Standard for new aircraft, identified three options for applying that Standard: to new aircraft "types" (designs) only; to all newly delivered aircraft; or to all new and in-service aircraft. Recent analysis done by the observer organization on historical trends in new aircraft efficiency suggests decreasing gains in average new aircraft due to a lack of new aircraft designs. A CO_2 Standard covering new aircraft types only is an inferior means of reducing emissions. Such a Standard could actually increase emissions by providing manufacturers with a disincentive to introduce new aircraft designs. Given pressing resource and time constraints faced in expeditiously developing a Standard, the observer invited CAEP to recommend that a CO_2 Standard be developed for application to all newly delivered aircraft.

2.5.4.12 An observer noted that this approach suggested a technology-forcing perspective in CAEP and reminded the meeting that the CAEP principles are technical feasibility, economic reasonableness, and environmental benefit, and that technology-forcing is not one of the principles of CAEP.

2.5.4.13 With regard to the two potential applicability thresholds: 32.5 tonnes maximum takeoff weight (MTOW) with a maximum seating capacity of at least 20 passengers, and 50 tonnes MTOW without an associated seating capacity, the observer summarized an analysis of the global fuel burn coverage of these two options for newly delivered aircraft. It was estimated that the 32.5 tonne MTOW threshold would cover approximately 96% of the fuel burn of new aircraft in 2008, while a 50 tonne threshold would cover between 88 and 90% of fuel burn depending on how regional jet manufacturers market model variants falling on either side of the threshold. Given the general desire to cover 95+% of global fuel burn, to maintain forward momentum in developing a Standard, and in the interest of developing a robust Standard resistant to gaming, the observer recommended that CAEP provisionally accept the 32.5 tonne MTOW threshold as the basis of ongoing work, subject to final confirmation at the CAEP/9 meeting. He further recommended that regional and business jets below the threshold continue to be included in CAEP's work to develop a certification requirement even if they are not subject to an associated regulatory level when the CO_2 Standard is initially implemented.

2.5.4.14 An observer stated that a more inclusive approach to evaluate a metric and certification scheme for all subsonic jet aircraft is more likely to avoid future market distortion. It was therefore recommended that the scope of CO_2 Standard work during the CAEP/9 cycle include initial evaluation of a more inclusive approach in parallel with the consideration of the MTOW threshold. Final recommendations on applicability could be made in a Steering Group meeting early in the CAEP/9 cycle. Such an approach would ensure due consideration is given to all categories of subsonic jet aircraft and will minimize unintended consequences. The observer believed that leaving the threshold open now will not delay the agreeing of a metric for CO_2 Standard related work in this coming CAEP cycle. He also expressed his commitment to devote the appropriate resources and to complete the necessary work to deliver the material that CAEP needs during the CAEP/9 cycle, even given the above recommendation to keep the applicability threshold open at this time. It should be further noted that limitations on the applicability of a new CO_2 Standard at any point should not be construed to limit the scope of the analysis nor participation in relevant work.

2.5.4.15 An observer, speaking on behalf of a group of States stressed that work on a CO_2 Standard should be given top priority in the CAEP/9 work programme. The three essential elements of such an effort are that the Standard be timely, well structured and effective. To ensure a successful outcome within this timeframe, it was proposed that the work be taken forward in a number of stages, with time built in for evaluation, and that the technical group be given responsibility for agreeing to the timetable for the work. It was also proposed that, for CAEP/9, the certification requirement should apply to larger new aircraft types greater than 50 tonnes. The CAEP was also invited to commit the resources, during the CAEP/10 cycle, for the work to set a regulatory Standard for new aircraft types and to extend the applicability to smaller and "in-production" aircraft. Undertaking the above tasks in parallel, with sufficient resources and commitment, it should be possible for a draft certification requirement to be considered at the CAEP/9 meeting in February 2013. It is anticipated that the applicability of such a requirement would initially be new aircraft types after 31 December 2015. There would initially be no associated regulatory level but it would provide transparency on the CO_2 emissions of different aircraft types and configurations. The observer committed to provide a co-leader of the CO_2 Standard task from the group of countries represented by him.

2.5.4.16 A member, noting the urgency and importance of the CO_2 Standard, suggested that a new working group or task force be created to undertake this task. He pointed out that aircraft performance is a system level issue and therefore would necessitate formation of a new group. He also recommended that the analysis on establishing a lower applicability threshold be continued. Ideally, all aircraft should be included but a thorough study based on technological feasibility, environmental benefit and economic cost is needed to make a decision. Therefore, a decision should be made in a Steering Group meeting after relevant analysis has been completed. The member also committed to provide experts for the effort leading to establishment of a CO_2 Standard.

2.5.5 **Discussion and Conclusions**

2.5.5.1 A member expressed her concern with the proposal of establishing a new group. She was concerned with splitting the resources when the necessary expertise already resides in WG3. The member with the original proposal replied that a new group will avoid multiple levels of approval. He was concerned with overloading WG3 and noted that the same expertise will be used whether it is in a task group under the working group or a in a separate working group.

2.5.5.2 In answer to a question, the Secretary clarified that a Standard does not always need to be adopted at fixed three year intervals, as long as the appropriate approval procedures are followed. The three year interval has worked well in the past in terms of coordinating with amendments of other Annexes and also the typical work duration of a majority of CAEP work items has so far been three years.

2.5.5.3 Some members emphasized that it is generally desirable that all jet aircraft be covered in the analysis and a decision on a lower applicability threshold may be premature. It was suggested that data analysis to be conducted in the future to determine this threshold. One member noted that expanding the analysis to all jet aircraft has the danger of market distortion since the lower weight turbojets compete with other types of aircraft. He also pointed out the trade-off between expanding the scope and the length of time to complete the task.

2.5.5.4 Several members committed to providing resources to the group in order to ensure timely and effective completion of the CO_2 Standard task.

2.5.5.5 A member expressed his doubts about application of a new Standard to any aircraft except new certifications since it is not clear how it will be applied or what the economic cost could be.

2.5.5.6 A member inquired whether the meeting would discuss the choice between classical pass-fail certification test and a corporate average type of Standard since these were mentioned by the Chair. The working group representative clarified that the WG did not intend to bring this issue as something to be decided at CAEP/8, since an analysis of the advantages or disadvantages of a corporate average approach had not yet been conducted.

2.5.5.7 A member agreed with the high priority accorded by ICAO to CO_2 Standard but highlighted that CAEP should not lose sight of other mandates from ICAO. Therefore, an appropriate balance in priorities needs to be maintained.

2.5.5.8 The Chair acknowledged the high quality of presentations and the subsequent discussion on the issue of a CO_2 Standard. He summarized that the main topics identified were applicability thresholds (e.g. MTOW), to which aircraft this Standard would apply (e.g. new aircraft types, in-production, in-service) to, and whether this Standard would be a pass-fail type or use some other criteria.

He also highlighted that timelines and resources would have to be identified to complete this task in the most efficient manner. The discussion was very helpful in understanding and setting out various positions and priorities. The Chair requested that these issues be further discussed under the future work agenda item.

2.6 EMISSIONS – OPERATIONS RELATED ISSUES

2.6.1 Prior to the discussion on Agenda Item 2, D/ATB briefly presented the role of ATB in support of CAEP activities and, in particular, on the ongoing coordination with ANB on operational measures to address aviation emissions, assuring the commitment of both herself and D/ANB to continue this coordination and cooperation between these Bureaux. D/ATB then introduced D/ANB who provided a presentation on overall initiatives undertaken under ANB and suggested next steps and specific areas where CAEP and the operational community could benefit from further collaboration.

2.6.2 She emphasised that Secretariat would do its part and presented concrete steps put in place to ensure coordination and transparency. She proposed next steps for pursuing the collaboration between the environmental and operational "talent" and offered to brief CAEP on the developments in the operational efforts that benefit environment. The main area where the support of the committee was sought was on the development of methods to assess environmental benefits of operational measures. She proposed to establish a "measures" sub-group of the Regional Planning and Implementation Groups (PIRGS) and develop a training programme in this area.

2.6.3 A member stressed that ICAO has several panels, dedicated for safety, economic and security aspects but that there is a committee with the remit on environmental-related issues and that all environmental considerations are tasked within CAEP. She added that it was obvious that while performing these activities, coordination between the other panels was necessary.

2.6.4 Several members and observers welcomed the presentation made by D/ANB and stressed the importance of non-duplication, coordination and cooperation among ATB, ANB and CAEP. A member suggested that ANB provide updates to CAEP and SG meetings on the operational work. An observer suggested that when discussing these issues under the Future Work agenda item, members from ANB attend the meeting.

2.6.5 The Chair summarized by saying that he heard many magic "Cs" in the presentation, i.e. commitment, collaboration, cooperation, coordination and CAEP, and that the Committee was pleased to hear that it could count on the support from ANB for the development of some of its tasks. He further stated that the suggestions for next steps proposed by D/ANB would be brought to the attention of the meeting during the consideration of future work under agenda item 5. He also thanked both D/ATB and D/ANB for their contributions.

2.6.6 Next, a representative from the UNFCCC Secretariat provided the meeting with a brief update on the climate change negotiations under the UNFCCC, in particular the result of COP/15. He mentioned that, although bunker fuels were not directly addressed in the Copenhagen Accord, it recognized the scientific view to hold the increase in global temperature below 2 degrees Celsius and that it would be important for ICAO and CAEP to explore what this goal meant for international aviation. He also referred to the Accord's goals for mobilizing new and additional finance which would come from a variety of sources, including "alternative sources of funding" and that some might look to funding from international aviation in this regard.

2.6.7 He informed that to date 38 Annex I Parties provided information on their economy-wide emission reduction targets for 2020, but specific targets on international aviation were not included in the submissions. 23 non-Annex I Parties provided information on mitigation actions, and seven of them mentioned the transport sector, but no specific activities on international aviation were mentioned.

2.6.8 He concluded that the year 2010 provides an opportunity for ICAO and UNFCCC to further advance their work on a robust and efficient GHG regime for international aviation which will benefit the global environment and future generations.

2.6.9 **Report of Working Group 2**

2.6.9.1 The Co-Rapporteurs of WG2 presented the Group's report on activities since CAEP/7. The detailed work of the Group had been undertaken by four Task Groups as follows:

a) Task Group 1 (TG1): Land use planning and noise management;

b) Task Group 2 (TG2): Air Traffic Management;

c) Task Group 3 (TG3): Operational measures; and

d) Task Group 4 (TG4): Local air quality.

2.6.9.2 Ad hoc activities on the update and conversion of ICAO Circular 303 into an ICAO guidance manual and on the ICAO carbon emissions calculation methodology were also undertaken.

2.6.10 **TG1 – Land Use Planning and Noise Management Task Group**

2.6.10.1 The group continued to develop updates to the concept of a Balanced Approach to Aircraft Noise Management and to estimate the environmental impact of curfews on destination airports. It also investigated the use of Environmental Management Systems (EMS) among aviation organisations.

2.6.11 **TG2 – Air Traffic Management Task Group**

2.6.11.1 The group investigated approaches to environmental impact assessment as applied to CNS/ATM. It began development of ICAO guidance on computing, assessing and reporting on aviation emissions at national and global levels and the development of environmental indicators (EI). It also supported the IE efforts to make recommendations for noise, NO_x and fuel burn with respect to air traffic operational goals in the mid and long terms.

2.6.12 **TG3 – Operational Measures Task Group**

2.6.12.1 The group assessed the potential reductions of noise and gaseous emissions through the use of reduced takeoff thrust and deeper cutback and by the use of the Continuous Descent Operations (CDO). It contributed to the development of the CDO manual in cooperation with the IFPP and also studied the potential changes in noise exposure associated with steeper approaches.

2.6.13 **TG4 – Airport Local Air Quality Task Group**

2.6.13.1 The group completed development of new and updated chapters for ICAO Doc 9889, "Airport Air Quality Guidance Manual." It also had coordinated with FESG and MODTF on aircraft times-in-mode, and developed a report to CAEP and web text on the role of market based measures in a management framework for local emissions.

2.6.14 **Environmental Indicators**

2.6.14.1 The WG2 TG2 Environmental Indicators Ad-Hoc Group was tasked with conducting a review of the present guidance and practices in environmental performance indicators (EI).

2.6.14.2 While the guidance material is still not mature, key findings have been made and the basis for the development of ICAO EI guidance has been identified. However, there was a lack of consensus within the group on if and how this material should be used or further developed.

Findings

2.6.14.3 Differing purposes for EIs were identified:

- Regulatory and policy (decision support);
- Overarching environmental performance tracking (reporting);
- Support to (and harmonising of) local environmental performance tracking; and
- Support to and harmonising of confidential benchmarking

2.6.14.4 ISO environmental management system standards (e.g. 14031 & 14032) offer a sound basis for any overarching EI work within aviation and are the basis for the ICAO EI development. Consistency in the definitions of EI and in the quality of "feed data" collection and management are considered to be essential. The development and promulgation of simple EI tests would also help the industry to minimise unnecessary, poorly designed or inappropriate EI.

Proposed ICAO approach to Environmental Indicators

2.6.14.5 If EI guidance is to be developed through CAEP, it is proposed to:

a) only specify EIs to a level of detail that it (or its States or Institutions) wishes to monitor actively;

b) publish these EIs as those that Civil Aviation stakeholders are required to support;

c) publish generic aviation relevant Environmental Performance Management guidance complimenting the guidance already developed in the ISO international standards; and

d) establish a process to be led by WG2 – the existing EI ad-hoc group may suffice but an independent expert process may also be a possible solution, which would have a significant cost.

Discussion and Conclusions

2.6.14.6 The meeting congratulated the ad-hoc group of this task on its effort and progress in spite of the complexity of the task, and several members expressed the need to continue this task, subject to taking into account the priority and resources necessary for various tasks. Another member commented that they learned a lot from the report; including the complexity of indicators and that they are State-specific. As such, the work can inform ICAO, but cannot be published as is, and any potential future work needs to be weighed carefully given other priorities and lack of WG2 consensus – likely due to feasibility and lack of resources.

2.6.14.7 A member expressed the need to ensure non-duplication with other tasks, and informed that CANSO has been working on a similar task from a global perspective and coordination with this work should be explored in the future work programme.

2.6.14.8 The Chair concluded that there was general support for the necessity of this task, and that the future work of this task, including further development of an ICAO EI guidance; development of specific EIs with a focus on operational fuel efficiency and CO_2 emissions; and development of EI inputs to the work of Circular 303 replacement, would be further discussed in Agenda Item 5.

2.6.15 **Environmental Assessment of CNS/ATM**

Background

2.6.15.1 The WG2 TG2 Lead noted that the different impacts of aviation, including sustainability and socio economics issues, can be classified as having either a Local or a Global effect on the environment. CNS/ATM programmes have already demonstrated their capability in reducing significantly the environmental impact of aviation.

2.6.15.2 An agreed Environmental Impact Assessment methodology is needed to ensure the consolidation of the environmental studies that will be conducted in Research and Development programmes like SESAR and NextGen. It should be an integrated and systematic approach to assess how ATM programmes and improvements may impact the environment and should cover all phases of flight operation (ground, climb, cruise and descent). The ability to assess, predict, measure and monitor any changes in environmental performance allows decision-makers to incorporate information relating to the likely environmental impact of a CNS/ATM measure as a complement to other criteria such as safety, capacity, security and cost-efficiency, etc.

2.6.15.3 At present, there is no global and commonly agreed high level framework for conducting environmental impact assessment for CNS/ATM activities.

Progress to Date

2.6.15.4 A draft text based on guidance that is being developed within Europe was presented, based on three sources:

1) Output from the European Commission project CAATS[7] II (WP1.5);

[7] Co-operative Approach to Air Traffic Services

2) European Operational Concept Validation Methodology (E-OCVM); and

3) EUROCONTROL internal guidance material.

2.6.15.5 The draft material covered background information and guidance in four areas:

4) Review of Existing Environmental Impact Assessment Methods;

5) Principles of Environmental Assessment;

6) Assessment of Environmental Impacts Methodology; and

7) Validation plan of the Environmental Impact Assessment Method.

Discussion and Conclusions

2.6.15.6 Several members expressed their appreciation for the progress made and strongly supported the continuation of this task toward a globally acceptable high-level guidance material.

2.6.15.7 With regard to future work, a member highlighted the need to prioritize this task and suggested the scope of this task be clarified to enable specific inputs from more States in the future. Another member pointed out that the current report focused only on the assessment of climate change impact and suggested the future work should also include the assessment of noise impact. A member indicated that much of the material was based on European input and work would be required to make it applicable to all States. The member recommended separating the descriptive material from guidance and to develop high level material as future work.

2.6.15.8 Another member commented that CNS/ATM would provide all aviation stakeholders with a win-win situation in terms of safety, efficiency and environment, and that CAEP should closely monitor the progress of this task in cooperation with ANB.

2.6.15.9 The Chair concluded that further discussion on the future work and the priority of this task would be undertaken in Agenda Item 5, taking into account the views expressed by members.

2.6.16 **Update and Conversion of ICAO Circular 303 into an ICAO Manual**

2.6.16.1 Following-up on the discussion of GIACC's basket of measures in the development of the ICAO Programme of Action on international aviation and climate change, the CAEP SG meeting in September 2008 agreed that WG2 should streamline and integrate some of its deliverables towards updating the material contained in Circular 303 "Operational Opportunities Minimize Fuel Use and Reduce Emissions", concentrating efforts in one single comprehensive document instead of producing stand-alone guidance.

2.6.16.2 A new task was subsequently added to WG2 requesting the group to "produce new guidance document replacing Circular 303 with extended scope covering environmental impact assessment of CNS/ATM, methods for computing aviation emissions and environmental indicators and update existing material, in particular on ATM."

Progress to date

2.6.16.3 Due to the heavy CAEP workload, the late addition of this task to the work programme, and constrained resources, multiple States and Observer Organizations have indicated that they were unable to provide timely and substantial input and to complete a comprehensive review in advance of CAEP/8. As a result, in its current state, some chapters are limited in scope and not mature enough, and will be benefit from including more global perspective.

2.6.16.4 The ad-hoc group formed by the last SG meeting in June 2009 conducted a thorough review of the selected four chapters, as follows, which were presented to CAEP/8:

— Chapter 2 – Airport Operations;

— Chapter 6 – Air Traffic Management;

— Chapter 7 – Non-Revenue Flying; and

— Chapter 12 – The Effect of Load Factor on Fuel Efficiency.

2.6.16.5 While the whole of WG2 was involved in the original revisions to these chapters, only the ad-hoc group has participated in the detailed review. The meeting noted that the group received suggestions for additional revisions to some of the chapters. It was proposed that these comments, along with any other comments from WG2, be reviewed early in the CAEP/9 cycle.

2.6.16.6 The ad-hoc leader explained that the use of ad-hoc group and regular teleconferences proved to be an effective approach in progressing the discussions. He proposed that a similar approach be used for the work necessary to complete the review and expansion of the remaining chapters, and emphasized that the ability of key States and Observer Organizations to contribute to this task would be paramount to its completion.

Discussion and Conclusions

2.6.16.7 Several members appreciated the ad-hoc group for its leadership and substantial progress made in the selected chapters, and stressed the importance of this task in terms of providing States with updated guidance in this area. A member commented that Circular 303 is a very valuable material for use by all aviation stakeholders to reduce aviation fuel burn and welcomed the continuation of this task.

2.6.16.8 The Secretary added that Circular 303 was one of the bases for discussion of GIACC’s basket of measures in the development of the ICAO Programme of Action on international aviation and climate change, and CAEP has a timely opportunity to review the document and showcase the information to the world aviation community. She also pointed out that the updated information could provide the basis for the preparation of States’ Action Plans in line with the outcome of the High-level Meeting.

2.6.16.9 The meeting recognized that commitments from key States and Observer Organizations would be paramount to establishing the timelines and milestones in the production of the guidance. The meeting also noted the proposal for the use of a specialized group to continue the development of the guidance and that it proposed a web-based approach for its dissemination. Further discussion on this task will be undertaken in Agenda Item 5.

2.6.17 **Effect of Takeoff Thrust and Deeper Cutback on Noise, Emissions, Fuel Consumption and Climb**

2.6.17.1 WG2 presented at CAEP/7 the assessment on the effects of several variations of the PANS-OPS Noise Abatement Departure Procedures (NADP) on noise and emissions and produced guidance material (*Effects of PANS-OPS Noise Abatement Departure Procedures on Noise and Gaseous Emissions,* Circ 317).

2.6.17.2 As a follow-up to this work, CAEP/7 requested a study on noise and gaseous emissions effects from variations of takeoff thrust and from deeper cutback for individual aircraft at the same takeoff weight using the same Noise Abatement Departure Procedure (NADP). Aircraft evaluated in the study include the Airbus A320-200, A330-200, A340-600, and A380-800; the Boeing 737-700, 767-400ER, and 777-300; and the Bombardier CRJ900ER. The WG2 TG3 Lead presented the results of the study to the meeting.

Thrust Variation

2.6.17.3 ICAO PANS-OPS, Volume 1, Flight Procedures, Part I, Section7, Chapter 3 provides guidance with respect to noise abatement departure procedures. It discusses the conditions in which noise abatement procedures can be safely used and the envelope within which main flight parameters defining the procedure can be safely adapted for airport noise mitigation. Examples of such flight parameters are the minimum height at which engine thrust can be reduced and the minimum height at which flap/slat retraction and acceleration can be initiated.

2.6.17.4 The guidance includes two examples of noise abatement departure procedures. One procedure, called NADP1, is designed to mitigate noise at relatively short distances from the brake release point; and another procedure, called NADP2, is designed to reduce noise at relatively greater distances from the brake release point. Takeoff thrust variations and deeper climb thrust cutbacks for both NADP1 and NADP2 procedures were assessed in this study.

2.6.17.5 This study evaluates takeoff thrust effects at the same takeoff weight; and deeper cutback effect, with a minimum climb thrust, compared to the standard climb thrust.

2.6.17.6 For this study, the first case assumes a performance-limited takeoff weight associated with a 10-12% reduced takeoff thrust setting. The reduced thrust setting should correspond to a case halfway between full takeoff thrust and maximum permitted takeoff thrust reduction. According to an earlier study, this takeoff thrust setting value is believed to be close to the average thrust settings used in daily practice by the airlines.

2.6.17.7 The second case assumes a performance-limited takeoff weight associated with a 25% reduced takeoff thrust setting for some Airbus aircraft. This case is considered more representative of short stage length A320 operations in Europe.

2.6.17.8 The WG2 TG3 Lead highlighted that the flight procedures studied for this task were included for comparative purposes only: not all respective manufacturer's operations manuals include all the flight procedures presented in the study, and some of them therefore cannot be used in actual operations. Noise abatement flight procedures must be developed with advice from the appropriate manufacturer and approved by the State of the operator; and must comply with the safety criteria contained in PANS OPS. The specification of noise abatement procedures for a given airport requires dedicated environmental and safety studies that determine the need for such procedures and ensure the required levels of flight safety are maintained.

2.6.17.9 An operational and safety assessment of the procedures was not incorporated in this analysis.

Assessment of Noise and Gaseous Emissions Effects

2.6.17.10 The study found that reduced takeoff thrust result generally in a small increase in "close-in" noise, a decrease in NO_x, and in no change to CO_2. The effect on "distant" noise is inconclusive and/or airplane dependent. The study found that climb thrust generally has an impact on noise away from the airport, but this impact varies from one airplane to another and from one weight to another. Emissions results, both in terms of NO_x and CO_2, were also inconclusive and generally very small in magnitude.

2.6.17.11 For the thrust variations included in this study, no single departure procedure minimized overall noise and emissions simultaneously. Tradeoffs may be required between noise impacts close-in or further away from the airport, levels of NO_x versus CO_2 emissions, and finally noise abatement versus reductions in gaseous emissions.

2.6.17.12 An observer presented the view that the selection of takeoff thrust and deeper climb thrust cutback are not flight parameters that can be freely varied to optimise a NADP as stated in PANS-OPS. The observer explained that the selection of takeoff must balance economics, performance, maintenance requirements, aircraft status, weather, and runway conditions. Typically, the minimum takeoff thrust is used to relieve the engine from high combustion temperatures and reduce the maintenance overhaul costs while providing sufficient performance margins. However, full takeoff thrust may be selected because of runway contaminants, aircraft dispatch status, onboard systems status, and the weather conditions.

2.6.17.13 The observer expressed a concern that take-off thrust restrictions and reduced climb thrust selection for environmental reasons will have a very severe interference with the flight execution and is likely to reduce margins to safety, and asked this task to be refrained from its continuation.

Discussion and Conclusions

2.6.17.14 The meeting expressed its appreciation to WG2 for their analysis of this task. Regarding the concern expressed by the observer, several members were of the view that the scope of CAEP should continue to be for the environmental assessment aspects, while safety aspects should continue to be fully coordinated with other ICAO bodies and experts.

2.6.17.15 The Chair commented that safety is paramount for aviation and any safety concerns should be dealt with in the relevant bodies. CAEP should undertake the environmental assessment.

2.6.17.16 The Secretary clarified that ICAO is responsible for safety, security and environment of international aviation, and therefore all the work under ICAO must fully consider these three aspects before a final decision is made. CAEP was no exception and while CAEP is responsible for the environmental aspects, CAEP's constituency includes experts representing all aviation stakeholders and it is expected that they would bring other specific concerns to CAEP while participating in the development of the work. If any recommendation from CAEP could raise safety concerns, that should be properly flagged and brought to the attention of the relevant groups at an early stage. That is how CAEP has always operated and will continue to operate.

2.6.17.17 The meeting took note of the concern of the observer on safety, however regarding his statement that to "note the near impossibility to develop effective environmental operational procedures for close-in noise and emissions due to the inevitable safety implications and complex interaction with the dynamic state and operative limitations of the aircraft", the meeting could only note that this was the view of the observer but there was no concurrence from the meeting to such a statement. The meeting decided that this task was fully accomplished without further work being envisaged and no further work should be conducted until safety concerns have been evaluated and eliminated.

2.6.18 Assess and validate noise and emissions reductions accrued from the use of Continuous Descent Operations (CDO)

2.6.18.1 The WG2 TG3 Continuous Descent Operations (CDO)[8] task leader explained that CAEP/7 was informed of the benefits from the use of CDO and that these procedures were being developed locally on a widespread scale. CAEP/7 was also informed that there was not an internationally agreed definition or concept of CDA, and therefore the CAEP/7 requested the Secretariat to address it with ANC with a view to progressing this work in an appropriate ICAO body. As a result, work on a CDO manual was initiated by CAEP and a panel of the ICAO Air Navigation Commission: the Instrument Flight Procedures Panel (IFPP), and the draft manual will be submitted for approval of the ANC in 2010.

2.6.18.2 In addition, WG2 was tasked during CAEP/8 to update the assessment of noise and emissions reductions accrued from the use of CDO based on the definitions proposed by the IFPP. The results from early CDO trials in Europe and the US were previously reported and had identified environmental benefits from CDO that are of similar orders of magnitude across several airports.

Estimated Global CDO Benefits

Global Fuel and CO_2 Benefit Estimation

2.6.18.3 The approach taken for this very high level assessment was to pro-rate the typical range of fuel and emissions benefits so far found in CDO trials, to the calculated annual civil aircraft movements for 2006 for each aircraft category. The global movement numbers for each aircraft type were extrapolated from data for a single day in 2006 to a full year. An assumption of a 50 per cent achievement of CDO was taken to reflect the current disparities in achieving CDO. The aircraft movement data used only included medium and heavy civil fixed-wing turbojet aircraft.

2.6.18.4 Results from the estimate of the potential fuel and CO_2 benefits were given for 27 million calculated annual global movements in 2006 as follows (respectively in the case of the low and high benefit scenarios): between 500 thousand and 2.3 million of global tonnes fuel saved, between $250 million and $1.1 billion of global fuel saved and between 1.5 and 7 million of global tonnes CO_2 saved.

[8] Formerly continuous descent arrivals / approaches (CDA).

Global CDO Noise Benefit Estimation

2.6.18.5 Most of the CDO noise benefits arise at approximately 10 to 25 miles from touchdown and vary depending on base-case and the location of population centres. The noise reductions range from 1 to 5 dB. Thus the noise benefits can therefore be considered important, but would not normally be critical to an airport's mitigation regime.

Global NO_x Benefit Estimation

2.6.18.6 Unlike CO_2, NO_x emission is not proportional to fuel burn and any reduction in thrust produces a larger reduction in NO_x than from reduced fuel use alone. Since CDOs do provide a fuel burn reduction, a NO_x savings can be assumed, but could not be quantified in this analysis.

Other CDO Assessment Aspects

2.6.18.7 Implementation of CDO is accelerating in the US, Europe, Australia and Asia-Pacific. This will be further facilitated by the forthcoming ICAO CDO guidance manual.

Global CDO Performance Monitoring

2.6.18.8 Although there was no consensus, it is believed by some States and observers that ICAO should monitor CDO implementation and that CAEP should therefore consider adopting a performance monitoring role through its working arrangements and using one or more of the assessment approaches considered above.

Issues Identified

2.6.18.9 The group identified a number of issues related to the global assessment of CDO. The baseline (pre-CDO case) is different at every airport, in particular the population distribution and the fact that some amount of CDO happens naturally at most airports. This makes the validation of the results difficult, especially combined with the lack of global detailed information on CDO implementation. The task leader explained, however, that some local CDO assessments were made using data collected from actual operations, making those results reasonably consistent.

2.6.18.10 The task leader explained that local implementation of CDO is accelerating, which underscored the emerging need for a harmonized local assessment methodology and capability. The task leader suggested the document be the initial basis for further development of the harmonized methodology. In addition, some local, State, and international interests require a consistent performance monitoring capability.

Discussion and Conclusions

2.6.18.11 The meeting congratulated WG2 on the development of the CDO guidance manual in coordination with IFPP and the continued analysis of CDO. It noted the accelerated adoption of CDO procedures in many regions.

2.6.18.12 An observer enquired whether more inputs on the environmental benefits from CDO would be necessary and welcomed the possibility of having a more global perspective, and the task leader expressed appreciation for further inputs from worldwide regions to assess the environmental benefits of global international aviation operations.

2.6.18.13 Another observer sought clarification regarding coordination between this task and the development of CDO guidance manual, which the observer believed to be very important, and the task leader confirmed that there was coordination and that the analysis was based on the definitions in the CDO Manual.

2.6.18.14 The meeting noted the assessment of environmental benefits from CDO as a first order approximation and the different CDO performance assessment options identified, and will consider the need to continue with the task on the future assessment and harmonization of assessment methodology of CDO in Agenda Item 5.

2.6.19 **Computing, Assessing and Reporting Aviation Emissions**

2.6.19.1 The WG2 TG2 Lead presented on the development of ICAO guidance for computing, assessing and reporting on aviation emissions at national and global levels.

2.6.19.2 A review of applications and methodologies for computing, assessing and reporting civil aviation fuel burn and CO_2 emissions was presented and should be considered a work in progress. A refined version of the report could also serve as input material for the update of ICAO Circular 303.

2.6.19.3 Along with the different applications, methodologies were described for computing fuel burn (and hence CO_2 emissions) from operating aircraft on a gate-to-gate basis. Where appropriate the methodology included the turn-around phase to include APU fuel burn.

Development

2.6.19.4 Although the original geographical scope was for national and global fuel burn, CAEP SG meeting in 2008 accepted to add the local level (fuel burn in the LTO phase below 3000ft) in the guidance on the basis that:

a) Local CO_2 emissions form part of the carbon inventory reporting applications such as EMEP[9]/CORINAIR[10] where CO_2 is reported for LTO and 'Cruise'[11];

b) Airport authorities need to be able to calculate their carbon footprint to demonstrate "their slice of the pie"; and

c) Quantifying the emissions that result from airports often being the constraining point in the air traffic system.

d) The guidance was not intended to rival other publications that address the subject of computing aviation emissions. Instead, this guidance drew on work developed, reported and promoted by industry, standards organisations and international bodies. As such, there was some concern regarding the duplicative nature of the draft guidance.

[9] EMEP - European Monitoring and Evaluation Programme
[10] CORINAIR - The Core Inventory of Air Emissions in Europe (http://www.eea.europa.eu/publications/EMEPCORINAIR)
[11] Cruise: All phases of a flight above 3000ft with respect to Aerodrome Elevation.

2.6.19.5 Guidance on the calculation of other categories of aircraft emissions, i.e. N_{Ox}, HC, CO, SO_x, PM from main engines, APU or brake/tire wear was outside the scope of this work for CAEP/8.

Scope and limitations

2.6.19.6 The scope of the task was restricted to the compilation of methods and tools for calculating and reporting aircraft fuel burn and CO_2 emissions and their possible applications. The term aviation could include all emissions from all sources related to air transport activities during all life-cycle phases. Other pollutants could be covered in a future issue.

2.6.19.7 The geographical scope of the guidance covers aviation CO_2 emissions at local (within the limits of the ICAO LTO certification cycle), State, and global (worldwide or ICAO region) scales.

2.6.19.8 The guidance document should allow a reader to choose the aircraft fuel burn calculation method that is most suitable for a particular application.

Report Structure

2.6.19.9 The global layout and structure of the draft guidance is as follows:

e) review of application themes: An inventory of aviation emissions applications;

f) gap analysis;

g) methods catalogue; and

h) reporting.

2.6.19.10 The TG leader informed that the bulk of the material was had been developed (around 90 per cent) and that a few more items needed to be completed. The final review would still need to be undertaken. He suggested that the material could be used as part of the new guidance replacing Circ. 303.

2.6.19.11 An observer presented ACI's new manual, providing guidance material for airport operators wishing to manage greenhouse gas emissions. The document draws the threads of some guidance documents and should assist airport operators with allowing comparisons of airport inventories and achievements.

Discussion and Conclusions

2.6.19.12 The meeting congratulated WG2 on the development of the draft guidance document. Several members commented on its usefulness and suggested incorporation into the manual replacing Circular 303. A member suggested the continuation of this task under MODTF. Another member commented that 90 per cent of the work was completed with remaining 10 per cent of the work to be devoted to its review, and the material should be left for inclusion in Circular 303.

2.6.19.13 In concluding, the Chair re-emphasized that 90 per cent of the work was completed, and that further discussion on the continuation of this task, including which working group would undertake this task and possible future work for Circular 303, would be undertaken in Agenda Item 5.

2.6.20 Update of Airport Air Quality Guidance

2.6.20.1 The WG2 TG4 lead presented on the development of airport air quality guidance information to assist States in implementing best practices. This group was also tasked with providing continued coordination with FESG on “times-in-mode” in relation to modelling capabilities, and preparing a report and web material that describes the various technical, operational, mitigation and market-based measures available to address aircraft emissions impacting local air quality.

Coordination with FESG on “Times-in-Mode”

2.6.20.2 The use of performance based times-in-mode (TIM) versus the certification values task did not require coordination with FESG, but WG2 TG4 did monitor the work of MODTF. Although no specific modification to the Guidance Manual was identified, the group noted that the MODTF NO_x stringency policy assessment activity includes a sensitivity test for performance based TIMs.

Develop and update the Airport Air Quality Guidance (Doc 9889) to include dispersion modelling, measurements, and revision of the inventory chapter

2.6.20.3 ICAO published a preliminary edition of Doc 9889 in 2007, including the Introduction, State Requirements, Emissions Inventory, and the Spatial and Temporal Distribution of Emissions.

2.6.20.4 Updates to the Aircraft Inventory and Road Vehicle chapters have been prepared and two new chapters on Dispersion Modelling and Air Quality Measurements have been completed. The new text was presented to the meeting for approval.

2.6.20.5 The updated document provides detailed information on regulatory air quality drivers, which aircraft and non-aircraft emissions sources to address, how to calculate the emissions, how to calculate the resulting air pollutant concentrations, and how to measure airport ambient air quality and use modelling calculations to confirm the local air quality situation.

Development of remaining chapters

2.6.20.6 The task leader informed that the two remaining chapters: Mitigation and Interrelationships were proposed to be developed during the early part of CAEP/9, subject to resources.

2.6.20.7 An observer reported that a case study has been done for Zurich airport to investigate the effects of applying different levels of information for emission inventory calculations and concentration modelling. The results of this study could be used to inform any decision making process for users who would wish to conduct similar assessments. He informed that the development of material for the chapters on Mitigation and Interrelationships had been initiated and that these final two key chapters of the manual are fundamental and to the usefulness of the document.

2.6.20.8 Two observers offered to provide resources to ensure the completion of this task. They also proposed to deliver a draft of these two chapters to the first Steering Group Meeting of CAEP/9 expected in November 2010.

Discussion and Conclusions

2.6.20.9 Two members expressed a concern regarding the approaches and models used in Chapter 4 (Dispersion Modelling), and requested that another approach and model currently used by these States (PolEmiCa model) be incorporated in a balanced manner.

2.6.20.10 The Chair and the WG2 TG4 lead responded that, since the draft guidance manual was the outcome of three-year thorough discussions since CAEP/7 and all inputs were incorporated before reporting back to this meeting, additional inputs could be incorporated only if necessary in the future work.

2.6.20.11 An observer pointed out that the approaches described in Chapter 4 of the guidance do not refer to a specific model, instead, they only provide a generic description, and therefore any model in use would be covered in this Chapter. The observer also pointed out that the TG4 only analyzed models that were already reviewed and in use within CAEP, and therefore prior to incorporation of a new specific model in the guidance, it would need to be sent to MODTF for review.

2.6.20.12 The meeting approved the additional and revised guidance manual chapters proposed by TG4, and decided to make the updated manual available through the ICAO public website. It also concluded that the possible update of Chapter 4 in the future would be discussed in Agenda Item 5.

Recommendation

2.6.20.13 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 2/4 — Update to Airport Air Quality Guidance Manual (Doc 9889)

That the ICAO Airport Air Quality Guidance Manual (Doc 9889) be updated with the material contained in Appendix C to the report on this agenda item, and that it be published on the ICAO public website free of charge.

2.6.20.14 Regarding the development of the Mitigation and Interrelationships chapters during the CAEP/9 cycle, several members and an observer expressed their support for the development of these new chapters. A member expressed concerns with the development of an Interrelationship chapter, in particular the relevance of addressing the interrelationship between LAQ and climate change, and reminded the meeting of the issue of resources for completion and review of the guidance material.

2.6.20.15 The Chair concluded that the development of new chapters would also be discussed in Agenda Item 5.

2.6.21 **Environmental Management Systems**

2.6.21.1 The WG2 TG1 EMS Task leader noted that at the last CAEP meeting in February 2007, WG2 was assigned a task under the CAEP/8 work programme to deliver a report providing information on the use of EMS and, as appropriate, make recommendations on how the Committee could promote the use of EMS within the aviation system.

2.6.21.2 To complete these two tasks successfully, a questionnaire was proposed and developed to gather information for the report, to be distributed to aviation organizations worldwide. The Secretariat sent the questionnaire and an accompanying introductory State letter in May 2008. The questionnaire and letter were then widely distributed by States and industry associations. The information collected through this questionnaire forms the basis of the report to CAEP/8.

Survey response and results

2.6.21.3 Over a six month time period, responses were received via mail, fax, e-mail, or through the questionnaire software program (interactive electronic tool). At the end, all questionnaire responses were input into the questionnaire software program. Initially, 254 responses were received from organizations worldwide. As a result of the data validation process, which consisted in reviewing data and resolving inconsistencies, 233 responses were selected to form the basis of the report.

2.6.21.4 117 questionnaire respondents apply EMS Standards or guidelines, with the majority having an ISO 14001 v2004 certified EMS in place. Among them, 96 percent recommended that other organizations implement one. Many of the remaining 116 respondents use other types of environmental programs and procedures mainly because of unfamiliarity with EMS approaches. Among them, 79 plan to implement one.

2.6.21.5 As a result, EMS implementation guidance specific to the aviation industry was requested.

Task report and recommendations

2.6.21.6 Based on survey responses, TG1 developed a Report on Environmental Management System Practices in the Aviation Sector that contains aggregated questionnaire responses and two recommendations agreed from WG2 TG1:

i) **disseminate report information**. Within the first year of the CAEP/9 cycle, ICAO should make the information contained in this report publicly available; and

j) **develop EMS guidance**. A standalone EMS guidance document should be developed for the end of the CAEP/9 cycle.

Report dissemination proposal

2.6.21.7 WG2 TG1 developed and presented a proposal for disseminating the final report to States, respondents, and the public in a manner consistent with the confidentiality statement provided in the questionnaire. It was recommended that the report be disseminated in the following ways:

a) publish on the ICAO public website free-of-charge; and

b) distribute by letter to CAEP States and observers, and to all survey respondents.

Discussion and conclusions

2.6.21.8 The meeting welcomed the completion of the report, approved the report, and accepted the dissemination proposal presented by WG2 TG1.

Recommendation

2.6.21.9 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 2/5 — Report on Environmental Management Systems Practices in the Aviation Sector

That the report contained in Appendix D to the report on this agenda item be published as an ICAO document on the ICAO public website free of charge.

2.6.22 **Creation of an AIRE-like Partnership to Focus on Main Traffic Flows and Reduce Emissions between Europe and South America**

2.6.22.1 A member on behalf of four European CAEP members and an observer presented the European interest in encouraging the development of activities to reduce the environmental impact of aviation at international level and to broaden and extend the experience and benefits from ongoing initiatives such as AIRE and ASPIRE to other world regions such as the Europe - South America oceanic routing areas (South Atlantic routes) with a further perspective to cover the entire trans-Atlantic area.

2.6.22.2 Several members welcomed and supported this initiative, and the meting acknowledged the need for collaboration and establishment of synergies between different countries and authorities to improve aviation efficiency and reduce fuel burn hence CO_2 emissions.

2.6.22.3 The Secretariat suggested the presentation of the working paper to the South Atlantic Regional Group. The Secretary emphasized that, as more and more initiatives emerge, the global harmonization on the design, implementation and environmental assessment of these initiatives would be crucial before we spread-out initiatives to different areas in order to obtain maximum synergy.

2.6.23 **ICAO Carbon Emissions Calculator**

2.6.23.1 The Aviation Carbon Calculator Support (ACCS) ad hoc group lead presented a review of the progress made in the development of an aviation carbon emission calculator methodology both by this group and its predecessor, the Aviation Carbon Estimation (ACE) ad hoc group, and a proposal for future enhancements.

2.6.23.2 The group successfully developed an impartial, transparent methodology for computing the CO_2 emissions from passenger air travel. In June 2008, ICAO posted on their website a Carbon Emissions Calculator that estimates the CO_2 emissions from air travel based on this methodology for use in offset programs. The Calculator allows passengers to estimate the emissions attributed to their air travel through a simple interface that requires the user to enter only their origin and destination airports, and their class of service. The methodology used by the calculator applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried. The ICAO Carbon Emissions Calculator can be accessed through the ICAO website: www.icao.int by clicking the link labelled "ICAO Calculator" on the left side of the homepage. The ICAO website provides the public with access to documentation of the methodology used by the Calculator and answers to a set of frequently asked questions.

2.6.23.3 The UN Environment Management Group (EMG), who is responsible for the Climate Neutral UN initiative, formally adopted the Calculator as the tool for computing CO_2 emissions from air travel. With a view to facilitating the use of the ICAO Calculator by other UN agencies and organizations, in August 2009, ICAO provided them with an enhanced interface to the carbon emissions calculator, which has since received positive feedback. To further facilitate inventory preparation, ICAO facilitated the integration of the Calculator directly into three UN Organizations' travel approval systems.

2.6.23.4 The ACCS group also explored the development of a methodology to compute the CO_2 emissions from air freight. The group suggested that potential methodologies used to compute emissions from cargo carried onboard a passenger aircraft will need to be distinct from that used to compute emissions from cargo carried on a dedicated freight aircraft. It was noted that transport routes and modes for cargo are not always clear, hence, leading to potential inaccuracy in emission estimation. The following approach for developing a cargo emissions calculator was proposed:

1) (For belly cargo only). Use the passenger/cargo ratio with the existing passenger calculator methodology to attribute CO_2 emissions to the cargo being carried. This could initially be done on a weight basis to be refined to incorporate a DIM (dimensional weight) factor, if appropriate. This will allow an initial calculator to be made available in the very near term. In support of this activity, IATA will investigate with its airline offset program partners their willingness to develop cargo carbon emissions (per freight weight) based on actual airline data and assess if they would be willing disclose these results as a means of refining these results. This level of information will also enable an assessment of the margin of error associated with this approach.

2) (For dedicated freight aircraft only). In the near term, CAEP should develop a distance-based methodology for computing cargo emissions. In doing so, it will seek support from IATA to help with an assessment of the level of accuracy achieved. An assessment of the range of errors from using this method should be undertaken, including an assessment of the errors associated with segments of the trip being carried by a mode of other than aviation. When introduced to the public, the documentation of the errors and limitations of the methodology should be transparent. The ACCS lead noted that the CAEP experts would be unable to comment on emissions from other transport modes and that another source for this information would need to be identified. It was also noted that this approach would allow for those shippers with more detailed information on the route/mode taken by their cargo to apply that information to refine their result. This approach was known internally to the ACCS group as "Option 1" of the cargo methodology.

3) (For belly cargo and dedicated freight aircraft). Over the longer term, develop a route and aircraft type independent methodology through the use of top-down modelled or measured fuel consumption data. This approach was known internally to the ACCS group as "Option 2." Again, full disclosure regarding the accuracy of the

result given the inability of the consumer to know the route taken by the cargo would be required before making the calculator available to the public. IATA will pursue obtaining the necessary data from its member airlines, and noted that the ability to implement this approach will depend on data availability and airlines' willingness to disclose it.

2.6.23.5 While the existing passenger methodology has been widely accepted, it is not without limitations. One area in particular is its current dependence on the CORINAIR data set for aircraft fuel consumption information. Because the CORINAIR data set has not been updated to reflect the latest generation of aircraft, improvement of the Calculator would be sought to compute CO_2 emissions for the Airbus A380, the current generation Boeing 737 aircraft, and the Embraer E190 and E195, among others.

2.6.23.6 With the objective of continuous improvement of the existing passenger methodology, the following approach for improvement was proposed that follows 3 parallel tracks:

Update the current database

— Incorporate city-pair level load factor data collected by ICAO and pursue filling gaps through IATA;

— Incorporate air carrier level seating configuration data, where available;

— Pursue obtaining CORINAIR-like data for the missing aircraft types from the aircraft manufacturers; and

— Consider refining the premium/economy multiplier used as well as its basis (space vs. weight).

Update the methodology and underlying data sources (modelled)

— Pursue obtaining flight-level global emissions inventories generated by AEDT/SAGE, AEM III, Aero2K, and FAST (the aviation GHG models evaluated by CAEP) on a regular basis. These results would be merged into a single ICAO database of modelled fuel consumption (or CO_2 emissions)

Transition from modelled estimates of fuel consumption/CO_2 to measured values

— Pursue obtaining measured fuel consumption (including type of fuel consumed – i.e. alternative fuels) data at the city pair level from IATA and IBAC, and other relevant bodies such as the European Low Fares Airline Association (ELFAA). In support of this step, IATA will be asked to confirm whether airlines are willing to disclose such information to ICAO, noting that any data sharing by IATA member airlines will be subject to an assessment of appropriate disclosure levels including data confidentiality issues and intellectual property rights.

2.6.23.7 An observer presented their views regarding various aspects of the ACCS activity on the Calculator, notably the proposed approach to enhance the passenger methodology and the extension of this methodology to air freight. In addition, concerns were raised about the specific use of the Calculator by third parties.

2.6.23.8 The observer believed that the ICAO passenger methodology for estimating CO_2 emissions presents a valuable tool provided it is used for its intended purpose and recognizing that it produces more accurate results when used in combination with more accurate input data. For this reason, the observer recommended that CAEP continue refining and improving the passenger methodology, working with relevant industry bodies.

2.6.23.9 For the air freight methodology, the observer was unconvinced that either of the Options described in paragraph 2.6.23.4 could eventually lead to a useful product that would be sufficiently robust and transparent and recommended the development of non-binding guidelines that would enable interested parties to develop an air freight methodology based upon specific operational data.

2.6.23.10 The observer also expressed concern regarding the use of the Calculator for the purposes of presenting users with a tool to distinguish between airlines, aircraft types or flights or commercializing Calculator data.

Discussion and Conclusions

2.6.23.11 The Secretary pointed out that development of the Calculator was very successful and a good result of cooperation and harmonization among aviation stakeholders, serving as one of ICAO's tangible results in addressing aviation emissions. She also clarified that the agreement with Amadeus was not intended for commercial purposes but aiming at cost-recovery. In addition, she mentioned that ICAO would receive information on the amount of air-travel carbon offsets through these systems.

2.6.23.12 An observer noted that contrary to data requirements for certification standards, data gaps can be filled by sources other than the manufacturers, so therefore requested the action item "ICCAIA to provide ICAO with compatible data to address the data gaps associated with the aircraft types" be changed to "compatible data or advice", which was agreed upon.

2.6.23.13 A member expressed a concern with regard to the use of global emissions inventory data from the model of the State (AEDT/SAGE) in terms of associated resources that could be necessary to cooperate with the activity. Although clarification was made by the ACCS lead on his intention not to put burden on the State's resources, the member was still of the view that providing support to the activities especially related to providing data on a regular basis would be unlikely, but she had no objection to further cooperation between ICAO, States and the industry on the further development of the Calculator's methodologies as resources permit.

2.6.23.14 Another member pointed out that future work could be accelerated considering the fact that the original Calculator was developed within a half year of intensive work; any update on Calculator should be conducted in a transparent manner; and the work on Calculator would be important in terms of possible carbon offsetting schemes in the future. The member suggested these points be considered for the discussions of the Calculator's future work.

2.6.23.15 An observer expressed the need to decide on the update of an average passenger weight of 100 kg assumed in the Calculator while MODTF assumed 91 kg.

2.6.23.16 The meeting confirmed that the purpose of the ICAO Carbon Emissions Calculator is not to present users with a tool to distinguish between airlines, aircraft types, or flights.

2.6.23.17 The Chair concluded that further discussion on future work on the Calculator would be undertaken in Agenda Item 5, while a small informal group would continue its discussion during the meeting, in particular on the issues of air freight methodology and STA/10’s fuel data collection form.

2.6.23.18 A member presented an overview of carbon footprinting work being carried out by his government. This work indicated robust carbon footprinting of aircraft operational networks can be carried out using Great Circle computations. Valuable carbon footprint information can be obtained using relatively basic datasets and commonly available software. Initial visualisation concepts to present a rapid transparent picture of carbon footprints have been developed. It was seen that over the FY 2008/9 the cumulative difference between actual and computed fuel use was just over 2%.

— — — — — — — —

TEXT OF PROPOSED AMENDMENT TO THE

**INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES**

ENVIRONMENTAL PROTECTION

**ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION**

**VOLUME II
AIRCRAFT ENGINE EMISSIONS**

. . .

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

. . .

Note.— Attention is drawn to the difference between the definition of "derived version of an aeroplane" in Volume I of Annex 16 and the definition of "derivative version" in this Volume.

Exhaust nozzle. In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.

. . .

PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION

. . .

1.4 Contracting States shall recognize as valid emissions certification granted by the certificating authority of another Contracting State provided that the requirements under which such certification was granted are not less stringent than the provisions of Volume II of this Annex.

1.5 Contracting States shall recognise as valid engine exemptions against an engine production cut-off requirement granted by a certificating authority of another Contracting State provided that the exemptions are granted in accordance with the process and criteria defined in the Environmental Technical Manual (ICAO Doc. 9501 Volume II).

CHAPTER 2. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

2.1 General

2.1.1 Applicability

2.1.1.1 The provisions of this chapter shall apply to all turbojet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when certificating authorities make exemptions for:

. . .

b) a limited number of engines over a specific period of time beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture of the individual engine.

2.1.1.2 In such cases, an exemption document shall be issued by the certificating authority, the identification plates on the engines shall be marked ~~"EXEMPT,"~~ "EXEMPT NEW" or "EXEMPT SPARE" and the grant of exemption shall be noted in the permanent engine record. Exemptions shall be reported by engine serial number and made available via an official public register.

2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines.

Note.— In considering exemptions, certificating authorities should take into account the probable numbers of such engines that will be produced and their impact on the environment. When such an exemption is granted, the certificating authority should consider imposing a time limit on the production of such engines for installation on new aircraft or on existing aircraft as spares. Further guidance on issuing exemptions is provided in the Environmental Technical Manual (Doc. No. 9501 Volume II).

. . .

2.1.4 Reference conditions

. . .

2.1.4.4 *Fuel specifications*

The fuel used during tests shall meet the specifications of Appendix 4~~, unless a deviation and any necessary corrections have been agreed by the certificating authority. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present~~.

. . .

2.2 Smoke

. . .

2.2.2 Regulatory Smoke Number

The Smoke Number at any of the four LTO operating mode thrust settings when measured and computed in accordance with the procedures of Appendix 2, or an equivalent procedure as agreed by the certificating authority, and converted to a characteristic level by the procedures of Appendix 6 shall not exceed the level determined from the following formula:

Regulatory Smoke Number = $83.6\ (F_{oo})^{-0.274}$
or a value of 50, whichever is lower

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual - Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines *(Doc 9501, Volume II).*

2.3 Gaseous emissions

. . .

2.3.2 Regulatory levels

Gaseous emission levels when measured and computed in accordance with the procedures of Appendix 3 and converted to characteristic levels by the procedures of Appendix 6, or an equivalent procedure as agreed by the certificating authority, shall not exceed the regulatory levels determined from the following formulas:

. . .

d) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 2007 and for which the date of manufacture of the individual engine was on or after 31 December 2012:

. . .

e) for engines of a type or model for which the date of manufacture of the first individual production model was after 31 December 2013:

1) for engines with a pressure ratio of 30 or less:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$D_p /F_{oo} = 7.88 + (1.4080 * \pi_{oo})$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$D_p /F_{oo} = 40.052 + (1.5681 * \pi_{oo}) - (0.3615 * F_{oo}) - (0.0018 * \pi_{oo} * F_{oo})$

2) for engines with a pressure ratio of more than 30 but less than 104.7:

i) for engines with a maximum rated thrust of more than 89.0 kN:

$D_p /F_{oo} = -9.88 + (2.0 * \pi_{oo})$

ii) for engines with a maximum rated thrust of more than 26.7 kN but not more than 89.0 kN:

$D_p /F_{oo} = 41.9435 + (1.505 * \pi_{oo}) - (0.5823 * F_{oo}) + (0.005562 * \pi_{oo} * F_{oo})$

3) for engines with a pressure ratio of 104.7 or more:

$D_p /F_{oo} = 32 + (1.6 * \pi_{oo})$

Note.— Guidance material on the definition and the use of equivalent procedures is provided in the Environmental Technical Manual – Guidelines on the use of Procedures in the Emissions Certification of Aircraft Engines *(Doc 9501, Volume II).*

. . .

APPENDIX 2. SMOKE EMISSION EVALUATION

1. INTRODUCTION AND DEFINITIONS

Note.— The procedures specified here are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system.

1.1 ~~Variations in the procedure~~ Any equivalent procedures to those contained in this Appendix shall only be allowed after prior application to and approval by the certificating authority.

. . .

2. MEASUREMENT OF SMOKE EMISSIONS

. . .

2.4 Fuel specifications

The fuel shall meet the specifications of Appendix 4~~. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.~~

. . .

2.5.3 Smoke measurement

. . .

h) the chosen sample sizes shall be such as to be within the range of 12 kg to 21 kg of exhaust gas per square ~~metre~~ meter of filter, and shall include samples which are either at the value of 16.2 kg of exhaust gas per square ~~metre~~ meter of filter or lie above and below that value. The number of samples at each engine operating condition shall not be less than 3 and e) to g) shall be repeated as necessary.

3. CALCULATION OF SMOKE NUMBER FROM MEASURED DATA

. . .

The masses of the various samples shall be calculated by

$$W = 0.348\, PV/T \times 10^{-2} (\text{kg})$$

where P and T are, respectively, the sample pressure in ~~pascals~~ Pascal and the temperature in ~~kelvin~~ Kelvin, measured immediately upstream of the volume meter. V is the measured sample volume in cubic ~~metres~~ meters.

. . .

APPENDIX 3. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS

1. INTRODUCTION

Note.— The procedures specified in this appendix are concerned with the acquisition of representative exhaust samples and their transmission to, and analysis by, the emissions measuring system. The procedures do not apply to engines employing afterburning. The methods proposed are representative of the best readily available and most established practice.

~~Variations in the procedure~~ Any equivalent procedures to those contained in this appendix shall only be allowed after prior application to and approval by the certificating authority.

2. DEFINITIONS

~~***Exhaust nozzle.*** In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.~~

. . .

APPENDIX 4. SPECIFICATION FOR FUEL TO BE USED IN AIRCRAFT TURBINE ENGINE EMISSION TESTING

The fuel shall meet the specifications of this Appendix 4, unless a deviation and any necessary corrections have been agreed by the certificating authority. Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

. . .

— — — — — — — —

APPENDIX B

ICAO Emissions Environmental Technical Manual
Volume II

Guidelines on the use of procedures in the
Emissions certification of aircraft engines

Environmental Technical Manual
Volume II

Guidelines on the Use of Procedures in the Emissions Certification of Aircraft Engines

TABLE OF CONTENTS

Page No.

NOMENCLATURE

Symbols and Units

Symbols and abbreviations employed in Volume II of this manual are consistent with those contained in Annex 16 – *Environmental Protection*, Volume II – *Aircraft Engine Emissions* (Third Edition, July 2008).

SECTION 1. INTRODUCTION

1.1 PURPOSE

1.1.1 The aim of Volume II of this manual is to promote uniformity in the implementation of ICAO Annex 16 — *Environmental Protection*, Volume II — *Aircraft Engine Emissions*, by providing guidance to certificating authorities and applicants regarding the intended meaning of the current Annex 16, Volume II emissions Standards and those specific procedures that are deemed acceptable in demonstrating compliance to these Standards.

1.1.2 This manual also provides guidance in the wider application of equivalent procedures that have been accepted as a technical means for demonstrating compliance with the emissions certification requirements of Annex 16, Volume II. Such equivalent procedures are referred to in Annex 16, Volume II, but are not dealt with in the same detail as in the Appendices which describe the emissions evaluation methods for compliance with the relevant Chapters of Annex 16, Volume II.

1.1.3 Annex 16, Volume II procedures must be used unless an equivalent procedure is approved by the certificating authority. Procedures presented in this manual should not be considered as limited only to those described herein as this manual will be expanded as new procedures are developed. Also, their presentation does not infer limitation of their application or commitment by certificating authorities to their further use.

1.1.4 References to Annex 16, Volume II relate to the Amendment 6 thereof.

1.2 FRAMEWORK

1.2.1 The basic framework of Volume II of this manual is a replication of the ICAO Annex 16, Volume II structure in order to ensure easy reference between the requirements and guidance. References in the Table of Contents are only made to a part of the requirements when there is an associated guidance material; otherwise the relevant paragraph has been "Reserved" for future use. There is minimal repetition of the requirement text in order to simplify the ETM content, lower maintenance costs, and reduce the danger of inconsistencies between Volume II and the ETM following future revisions. The requirement text is enclosed between two horizontal lines.

1.2.2 This first section provides general information while the second Section contains guidance material to ICAO Annex 16, Volume II. The format of the guidance material includes three types of information described as explanatory information, equivalent procedures and technical procedures. The definitions of these three types of information are as follows:

Explanatory information

- Explains ICAO Annex 16 emissions Standards language.

- States current policies of regulatory authorities regarding compliance with ICAO Annex 16 emissions Standards.

- Provides awareness of critical issues for approval of applicants' compliance methodology proposals.

Equivalent procedures

- An equivalent procedure is a test or analysis procedure which, while differing from one specified in Annex 16, Volume II, in the technical judgement of the certificating authority, yields effectively the same emissions levels as the specified procedure.

- The use of equivalent procedures may be requested by applicants for many reasons, including:

  a) to make use of previously acquired certification test data for the engine type; and

  b) to minimize the costs of demonstrating compliance with the requirements of ICAO Annex 16, Volume II by keeping engine test time, test bed usage, and equipment and personnel costs to a minimum.

Technical procedures

- A technical procedure is a test or analysis procedure not defined in detail in ICAO Annex 16 emissions Standards but which certificating authorities have approved as being acceptable for compliance with the general provisions the emissions Standards specify.

1.3 EMISSIONS COMPLIANCE DEMONSTRATION PLAN

1.3.1 Prior to undertaking an emissions certification demonstration, the applicant is normally required to submit to the certificating authority an emissions compliance demonstration plan. This plan contains the method by which the applicant proposes to show compliance with the emissions requirements. Approval of this plan and the proposed use of any equivalent procedure remain with the certificating authority. The determination of equivalency for any procedure or group of procedures must be based upon the consideration of all pertinent facts relating to the application.

1.3.2 Emissions compliance demonstration plans should include the following types of information:

a) Introduction: description of the engine emissions certification basis, i.e. the applicable Annex 16, Volume II Amendment and Chapter;

b) Engine description: type, model number and specific details of the basic configuration to be certified;

c) Engine emissions certification methodology: test concepts, equivalent procedures and technical procedures;

d) Test description: test methods to comply with the emissions Standards;

e) Measurement system: description of measurement and sampling system components and procedures, including calibration procedures, that are intended to be used to demonstrate compliance with the emissions Standards; and

f) Data evaluation procedures: emissions evaluation and adjustment procedures (including equivalent and technical procedures such as those provided in this manual) to be used in compliance with the provisions of ICAO Annex 16, Volume II appropriate to the engine type being certificated.

1.4 EMISSIONS CERTIFICATION REPORTS

1.4.1 Following completion of an emissions certification demonstration test, an applicant is normally required to submit an emissions certification report. This report provides a complete description of the test process and the test results with respect to compliance with the provisions of Annex 16, Volume II.

1.4.2 These reports should include the following types of information:

a) Basis for test approval: the approved emissions certification compliance plan for the engine type and model being certificated;

b) Description of tests: actual configurations tested and non-conforming items (with justification that they are not significant to emissions, or if significant, can be dealt with by an approved method), test methodology (including equivalent procedures and technical procedures), tests conducted, test data validity, and data analysis and adjustment procedures used;

c) Test results: data to demonstrate compliance with the provisions of Annex 16, Volume II regarding maximum emissions levels for the engine type being certificated; and

d) References.

SECTION 2. GUIDANCE MATERIAL

PART I. DEFINITIONS AND SYMBOLS

CHAPTER 1. DEFINITIONS

Exhaust nozzle. In the exhaust emissions sampling of gas turbine engines where the jet effluxes are not mixed (as in some turbofan engines for example) the nozzle considered is that for the gas generator (core) flow only. Where, however, the jet efflux is mixed the nozzle considered is the total exit nozzle.

EQUIVALENT PROCEDURE:

Defining the exhaust nozzle in this manner, where the fan and core nozzles are not coplanar, is problematic. With imperfect knowledge of the fan flow characteristics when discharged upstream of the core exit nozzle, the effective nozzle size may be ambiguous. This affects the extreme downstream location of the sampling probe or rake and causes problems in terms of a detailed traverse of the total exhaust nozzle. In order to obtain equivalent, but more accurate gaseous emissions measurements and representative samples, it is considered best practise to arrange the engine configuration in such a way as to separate the fan and core flows, without affecting the engine performance, and sample just the core flow. The above is equally applicable to both gaseous and smoke emission measurements, however for smoke, the dilution and mixing of bypass air also needs to be taken into account and this is covered under Appendix 2, paragraph 2.1.

CHAPTER 2. SYMBOLS *[Reserved]*

PART II. VENTED FUEL *[Reserved]*

PART III. EMISSIONS CERTIFICATION

CHAPTER 1. ADMINISTRATION *[Reserved]*

CHAPTER 2. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION ONLY AT SUBSONIC SPEEDS

2.1 General

2.1.1 Applicability

EXPLANATORY INFORMATION:

Part I of Annex 16, Volume II defines a derivative version[1] in terms of emissions certification, but this definition is only referred to in the Annex in the context of granting exemptions and does not specify how the rule should be applied to modifications of already certificated engine types. Many changes to a certificated engine, which are considered to be major from an airworthiness perspective, require an amendment or supplement to the Type Certificate (TC). However, this same modification(s) may have no or very little effect on the emissions characteristics of that engine. If Annex 16 is interpreted literally, these small effects would require a full investigation of compliance against the emissions certification requirements. This may not be necessary in many cases. The following guidelines have been developed in order to help determine whether a modification could be classified as a "no emission change" or if it would affect the emissions levels to such an extent that the engine type would need to be re-certificated against Annex 16, Volume II requirements. Of course manufacturers may elect to recertify to the latest requirements at any time.

TECHNICAL PROCEDURE:

1. **No emissions change**

The principle of a "no emissions change" criteria is that an engine would not need to be re-certified against the emissions requirements if the manufacturer could demonstrate that the modification(s) would result in a small cumulative change to the current certified engine emission levels. Cumulative change could be as a result of more than one change at a given time or multiple changes from more than one derivative version of the same engine being developed.

The potential determination of a "no emissions change" is limited to the following conditions:

i) If all of the characteristic levels prior to any modification are greater than or equal to 95 per cent of the existing ICAO Standard, the manufacturer must provide new engine emissions test data to demonstrate that the resulting characteristic levels after the cumulative changes since original emission testing will not exceed the existing ICAO exhaust emission Standard.

ii) If all of the characteristic levels are less than 95 per cent of the existing ICAO exhaust emission Standards, then new or related emissions test data and good engineering judgment

[1] Derivative version. An aircraft gas turbine engine of the same generic family as an originally type certificated engine and having features which retain the basic core engine and combustor design of the original model and for which other factors as judged by the certificating authority, have not changed.

based on substantive analysis may be an acceptable means to demonstrate that the resulting emission levels after the cumulative changes since original emission testing will not exceed the existing ICAO exhaust emission Standard.[2] Analyses should consider areas such as cycle changes, combustor and fuel nozzle design, or large changes in combustor inlet velocity profile or turbine cooling flows as discussed in paragraph 5 below.

iii) Any new emissions test data and/or engineering/technical analysis under subparagraphs (i) and (ii) must demonstrate that the cumulative changes in absolute emission levels, as compared to those of the original certification, are within:[3]

NO_X ± 3 g/kN
HC ± 1 g/kN
CO ± 5 g/kN
Smoke ± 2 SN

With respect to the tracking of cumulative changes, an applicant should maintain formal documentation of the technical basis for all approved "no emissions changes" for an engine model. The tracking list will be reproduced in each emissions certification dossier demonstration.

If a modification is classified as a "no emissions change", the characteristic levels for the derivative version will be considered the same as the parent engine.

2. **Changes requiring new emissions levels**

A change, or cumulative set of changes to the type design, which is/are not considered a "no emissions change" and thus affects the characteristic levels would require new characteristic levels to be determined during the certification program. This would normally be done through a new emissions certification test.

3. **Existing emissions certification basis retained**

If a modified engine remains on the existing type certificate, it may retain the existing certification basis of the parent engine[4] if the modification(s):

i) meets the demonstration criteria of 1(i) or 1(ii);

ii) results in a decrease of the absolute emissions levels;

iii) results in an increase of the absolute emissions levels below those prescribed in 1(iii);

iv) are necessary for improved safety and continued airworthiness (e.g. ADs).

[2] Good engineering judgment means judgments made consistent with generally accepted scientific and engineering principles and all available relevant information.
[3] Absolute emission level refers to the average of the measured emission levels corrected to reference conditions. This does not include application of the Appendix 6 statistical factors used to determine characteristic levels.
[4] In terms of emissions certification, the parent engine must have demonstrated emissions compliance and is not considered to be a derivative of an even earlier Standard itself.

4. Latest emissions Standards applied

An engine type should demonstrate compliance with the latest emissions standards when:

i) The engine requires a new TC;

ii) The engine modification(s) involves significant technical modifications and where, in the judgment of the certificating authority, the engine would not meet the definition of a derivative engine as defined in Annex 16, Volume II;

iii) The engine modification(s) does not meet the demonstration criteria of 1(i) or 1(ii);

iv) The engine modification(s) results in an increase in any of the absolute emissions levels below those prescribed in 1(iii) but which results in an exceedance of the existing ICAO Standard;

v) The engine modification(s) results in an increase in any of the absolute emissions levels in excess of those prescribed in 1(iii); or

v) There are significant future environmental impacts.[5]

5. Engineering analysis examples

The basic premise in assessing emissions effects of design changes from an engineering analysis perspective is that emissions are mainly affected by cycle changes, combustor and fuel nozzle design, or large changes in combustor inlet velocity profile or turbine cooling flows. A number of examples are provided below for illustration.

Cycle change

Annex 16, Volume II only requires the measurement of fuel mass flow by direct measurement to an accuracy of ±2 per cent (Attachment F to Appendix 3, d.) and thrust to an accuracy of ±1 per cent at take-off power and ±5 per cent at the minimum thrust. It may be that no affect on emissions beyond those prescribed in paragraph 1(iii) would be expected unless changes in air fuel ratio (AFR) result in a specific fuel consumption (SFC) change of more than 1 per cent.

Regarding combustor inlet temperature (T3), the Annex also states that the combustor inlet parameters shall preferably be measured but may be calculated from ambient conditions by appropriate formulas. Following a comparison on T3 detailed traverses versus typical certification test measurements, it was concluded that measurements are within ±6°F (ca. 3.5°C) of theoretical calculations. It may be that no affect on emissions beyond those prescribed in paragraph 1(iii) would be expected if the cycle T3 change is within ±6°F.

Combustor and fuel nozzle

Combustor and fuel nozzle changes include some key design characteristics that can significantly affect emissions (e.g. swirl cup flow, primary hole flow, front end cooling flow, injector

[5] The application of an old engine type to a new aircraft design could mean a life time of 30 years or more and thereby have a more serious impact on the environment than if the engine was produced for spare only.

atomization). Changes within or outside of production tolerances or part-to-part variation may indicate when a change would be important for emissions or else considered to be not measurable. No affect on emissions beyond those in prescribed paragraph 1(iii) might be expected if the changes are within current part-to-part variation or prescribed production tolerances.

Boundary conditions

Similar limitations to that for key design characteristics can be applied to that resulting from changes in boundary conditions. For example, if turbine cooling changes by 2 per cent, one could look at the resulting change in combustor flow distribution, and if the change is of the same order as typical part-to-part variation, it may be acceptable to conclude that no affect on emissions beyond those prescribed in paragraph 1(iii) would be expected.

2.1.1.1 The provisions of this chapter shall apply to all turbojet and turbofan engines, as further specified in 2.2 and 2.3, intended for propulsion only at subsonic speeds, except when certificating authorities make exemptions for:

a) specific engine types and derivative versions of such engines for which the type certificate of the first basic type was issued or other equivalent prescribed procedure was carried out before 1 January 1965; and

b) a limited number of engines beyond the dates of applicability specified in 2.2 and 2.3 for the manufacture of the individual engine.

2.1.1.2 In such cases, an exemption document shall be issued by the certificating authority, the identification plates on the engines shall be marked “EXEMPT,” and the grant of exemption shall be noted in the permanent engine record.

TECHNICAL PROCEDURE

1. **Introduction**

1.1 The current ICAO Annex 16, Volume II contains two different references to applicability dates:

- “date of manufacture for the first individual production model” which refers to the engine type certification; and
- “date of manufacture for the individual engine” which refers to the production date of a specific engine serial number.

1.2 The second reference is used in the application of global engine NO_X production cut-off Standards which specify a date after which all in-production engine models must meet a certain NO_X emission Standard. For example, all engines manufactured after 31 December 1999 must be compliant with the CAEP/2 NO_X Standard. It should be noted that these requirements are applicable to complete new “engine units” released into service as spares or for new aircraft installations, as discussed below, and not engine components required for maintenance aspects, overhaul, parts, etc.

1.3 It is recognized that there may be certain circumstances where it is justified to permit manufacturers to continue to produce new non-compliant engine units after a production cut-off date. These take the form of exemptions against the relevant Annex 16, Volume II provisions.

1.4 In order to promote a harmonized global approach to the granting, implementing and monitoring of these exemptions, this section provides guidelines on the process and criteria for issuing exemptions against a NO_X production cut-off Standard.

2. Exemption process

2.1 *Application*

2.1.1 The applicant should submit a formal application letter to the competent authority[6] for the manufacture of the exempted engines, signed by an appropriate manager, and copied to all other relevant organizations and involved competent authorities. The letter should include the following information in order for the competent authority to be in a position to review the application:

a) Administration

- Name, address and contact details of the applicant.

b) Scope of application for exemptions

- Engine type (model designation, type certificate (TC) number, TC date, emission TC basis, ICAO Engine Emissions Databank Unique Identification (UID) Number).
- Number of engine exemptions requested.
- Duration (end date) of continued production of exempted engines.
- Designate whether the proposed exempted engines are “spares” or “new”[7] and to whom the engines will be originally delivered.

c) Justification for exemptions

In applying for an exemption, an applicant should, to the extent possible, address the following factors, with quantification, in order to support the merits of the exemption request:

- technical issues, from an environmental and airworthiness perspective, which may have delayed compliance with a production cut-off;
- economic impacts on the manufacturer, operator(s) and aviation industry at large;

[6] In most cases this will be the Certificating Authority although it may vary depending on individual Member State processes.
[7] In the case that engines are to be “new” (installed on new aircraft), and would thus result in a larger negative environmental impact compared to spare engines, greater justification could be required to approve this application.

- environmental effects. This should consider the amount of additional NO_X that will be emitted as a result of the exemption. This could include consideration of items such as:

  - the amount that the engine model exceeds the standard, taking into account any other engine models in the engine family covered by the same type certificate and their relation to the Standard;

  - the amount of NO_X that would be emitted by an alternative engine for the same application;

  - impact of changes to reduce NO_X on other environmental factors, including community noise and CO_2 emissions;

- impact of unforeseen circumstances and hardship due to business circumstances beyond the manufacturer's control (e.g. employee strike, supplier disruption or calamitous events);

- projected future production volumes and plans for producing a compliant version of the engine model seeking exemption;

- equity issues in administering the production cut-off among economically competing parties (e.g. provide rationale for granting this exemption when another manufacturer has a compliant engine and does not need an exemption, taking into account the implications for operator fleet composition, commonality and related issues in the absence of the engine for which exemptions are sought); and

- any other relevant factors.

2.2 *Evaluation*

2.2.1 The evaluation of an exemption application should be based on the justification provided and the following definitions and criteria:

a) Use of engines

"Spare engines" are defined as complete new engine units which are to be installed on in-service aircraft for maintenance and replacement. It can be presumed that applications associated with engines for this purpose would be granted as long as the emissions were equal to or better than those engines they are replacing. The application should also include the other items described in paragraphs 2.1.1 (a) and (b), but it would not need to include the items specified in paragraph 2.1.1(c). For spare engines, the evaluation of the exemption application would be conducted for recordkeeping and reporting purposes, but it would not be done for approval of an exemption.

"New engines" are defined as complete new engine units which are to be installed on new aircraft. They can only be exempted from a NO_X production cut-off requirement if they already meet the previous standard (e.g. exemption from a CAEP/6 NO_X production cut-off is only possible if an engine type already meets the CAEP/4 NO_X Standard). Also, in order to gain approval for this type of exemption the applicant must clearly demonstrate that they meet the criteria for an exemption by including items described in paragraphs 2.1.1(a), (b), and (c). The competent authority may require additional information regarding the appropriateness of the potential exemption.

b) Number of new engine exemptions

Exemptions should be based on a total number of engines and time period for delivery of these engines, which would be agreed at time the application is approved and based on the considerations explained in 2.1.1.c) above. The number of engines exempted would normally not exceed 75 per engine type certificate and the duration would not exceed four years from the effective date of the production cut-off. Exemptions would only apply to non-compliant engine models on an engine type certificate.

Exemptions for new engines should be processed and approved by the competent authorities for both the manufacture of the exempted engines and the initial operator of the aircraft to which they are to be fitted. Given the international nature of aviation, civil aviation authorities of member states should attempt to collaborate and consult on the details of exemptions. In the case where engine type certification is done through a reciprocity agreement between or among member states, the states involved should coordinate on the processing of exemptions and concur before approval is granted.

As part of the review and approval process for exemptions from any production cut-off requirement associated with the CAEP/6 NO_X Standard, competent authorities may in some cases require a form of NO_X emissions offsetting, as appropriate within the context of aviation and considering an applicant's ability to utilize such measures. However, offsetting measures should be applied only when necessary in view of the number of engines for which exemptions are sought (e.g., greater than 30), duration and/or percent exceedance described in an application.

c) Exceptions

Unlimited exemptions should be granted for spare engines having emissions equivalent to or better than the engines they replace. Engines for use on state aircraft (e.g., military, customs and police) are not covered by the Chicago Convention and therefore excluded from these civil aircraft NO_X production cut-off requirements.

2.3 *Review*

The competent authority should review, in a timely manner, the application using the information provided in paragraph 2.1 and against the definitions/criteria in paragraph 2.2.

The analysis and the conclusions from the review should be communicated to the applicant in a formal response. If the application is approved, the response should clearly state the scope of the exemptions which have been granted. If the application is rejected, then the response should include a detailed justification.

3. **Registration and communication**

3.1 Oversight of the granted exemptions should include the following elements:

- The competent authority should publish details of the exempted engines in an official public register, including engine model, maximum number of permitted exemptions and use of engines.

- The applicant should have a quality control process for maintaining oversight of and managing the production of engines which have been granted exemptions against a NO_X emissions production cut-off Standard.

- Exempted engine plates should be marked with “EXEMPT [SPARE] or [NEW]”.

- An exemption should be recorded in the engine release to service document which states conformity with the Type Certificate (e.g., EASA Form 1, FAA Form 8130-3). Proposed standard text - “[New] or [Spare] Engine exempted from NO_X emissions production cut-off requirement”.

- The applicant should provide, on a regular basis and appropriate to the limitation of the approval, details to the competent authority on the actual exempted engines which have been produced (e.g., model, serial number, use of engine, aircraft type and serial number on which new engines are installed).

2.1.1.3 The provisions of this chapter shall also apply to engines designed for applications that otherwise would have been fulfilled by turbojet and turbofan engines.

EXPLANATORY INFORMATION

This sentence anticipates the introduction of future engine technologies. The emissions Standards in Chapter 2 would also be applicable to future engine types not categorized as a turbo-jet or turbofan but intended for use in international air transport services. The provision above is not directly applicable to turbo-prop engines for example.

2.1.2 Emissions involved [Reserved]

2.1.3 Units of measurement

EXPLANATORY INFORMATION

Smoke level is determined indirectly, by means of the loss of reflectance of a filter used to trap smoke particles from a prescribed mass of exhaust per unit area of filter. The result is a dimensionless smoke number “SN” which acts as a surrogate for, or indicator of, plume opacity. These smoke sampling and measurement procedures standardized in Annex 16, Appendix 2 are derived from SAE Aerospace Recommended Practice (ARP) 1179, Aircraft Gas Turbine Exhaust Smoke Measurement.

The smoke measurement Standard was developed for engines that generated smoke at considerably higher levels than are seen today. This affects the relative accuracy of the method. The measurement is considered (by the SAE E-31 committee that developed the method) to be no more accurate than ±3 SN. At smoke levels of SN 50-60 this represents an accuracy of 6% - 5%. At regulatory standards of 30 and below, relative accuracy becomes 10% - 20% or more.

2.1.4 Reference conditions

2.1.4.1 *Atmospheric conditions*

EXPLANATORY INFORMATION

The reference atmospheric conditions to which the gaseous emissions (HC, CO and NO_X) are to be corrected are the reference day conditions, as follows: Temperature = 15°C, Humidity = 0.00634 kg H_2O/kg of dry air, Pressure = 101.325 kPa.

2.1.4.2 *Thrust settings* [Reserved]

2.1.4.3 *Reference emissions landing and take-off (LTO) cycle*

EXPLANATORY INFORMATION

The exhaust emissions test is designed to measure hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen concentrations, and to determine mass emissions through calculations during a simulated aircraft landing-takeoff cycle (LTO). The LTO cycle is based on times in mode data during high activity periods at major airports for four modes of engine operation: taxi/idle, takeoff, climb-out, and approach. The mass emissions for these modes are combined to yield the reported emissions certification levels.

2.1.4.4 *Fuel specifications*

EXPLANATORY INFORMATION

Aircraft gas turbine engines use a variety of fuels. The specific fuel type and composition can and often does have a significant effect on engine emissions. Hence, it is an important factor when comparing emissions levels from one engine with those from another. It is particularly important in evaluating engine emission levels relative to a regulation that was based, in part, on an assumed fuel specification. The ICAO fuel specification defined in Appendix 4 is typical, but tighter, than the general Jet A aviation fuel specification. The requirement for emissions certification testing with a fuel that meets a particular specification provides a fixed point of reference for the engine. It provides for some degree of control over the effect of fuel composition on smoke formation and emission. It also helps in the assessment of the effects of changing technology.

2.1.5 Test Conditions [Reserved]

2.2 Smoke

2.2.1 Applicability [Reserved]

2.2.2 Regulatory Smoke Number [Reserved]

2.3 Gaseous Emissions

2.3.1 Applicability [Reserved]

2.3.2 Regulatory levels

EXPLANATORY INFORMATION

The date when a Standard in paragraph 2.2 and 2.3 becomes applicable within a certification project is related to the "... date of manufacture of the first individual production model ...". As this date is not always clear, certificating authorities have used the date of issue of the engine type certificate (TC) as a surrogate. The date is transparent as it is recorded on the TC and has therefore proven a useful approach in defining the certification basis for an engine type or model.

The Part 1, Chapter 1 definition of "Date of manufacture" refers to the date of the document issued to an individual production engine which attests compliance with the type certificate.

2.4 Information Required

2.4.1 General information [Reserved]

2.4.2 Test information [Reserved]

2.4.3 Derived information

EXPLANATORY INFORMATION

The "maximum Smoke Number" is formally defined as the greatest value of SN measured at any of the four thrust levels defined in 2.1.4.2. However, if a higher Smoke Number is measured at any other test condition between 7 per cent and 100 per cent of rated thrust during emissions certification tests, it is recommended that the higher value be reported as the "Maximum Smoke Number".

CHAPTER 3. TURBOJET AND TURBOFAN ENGINES INTENDED FOR PROPULSION AT SUPERSONIC SPEEDS

EXPLANATORY INFORMATION

During the CAEP/7 work programme, Working Group 3 reviewed the historic background on the development of the emissions Standards for turbojet and turbofan engines intended for propulsion at supersonic speeds and discussed general technology aspects of supersonic engines in comparison to those for subsonic applications. The output of this work was reported in CAEP/7-WP/10 in February 2007.

While further work, taking into account aircraft and engine development, was considered to be necessary to give clear recommendations on future changes to Chapter 3, the following preliminary observations and conclusions were agreed:

a) The current supersonic Standard seems to be outdated.

b) The Standard should not be applied for new engine projects.

c) Part III, Chapter 3 of ICAO Annex 16, Volume II would need to be revised.

d) The timescale for updating should take into account the technological development of any new SST engine project and be in line with the work to be undertaken on development of revised noise Standards.

e) Any alleviation compared to the current subsonic Standard would require detailed technical investigation.

f) In order for these conclusions to become recommendations work needs to be completed on whether the current subsonic LTO regulatory approach can be applied to supersonic.

g) Effects from cruise emissions from a potential fleet of supersonic business jets require more scientific understanding.

WG3 continues to monitor developments within the aviation industry and scientific community on this issue. WG3 has also agreed not to update Chapter 3 until a new SST engine project reaches a sufficiently mature level such that it can inform discussions on potential future revisions.

APPENDIX 2. SMOKE EMISSION EVALUATION

EXPLANATORY INFORMATION

The procedure for evaluating smoke emissions is an indirect measure of smoke plume visibility which is obtained by using a filter to trap smoke particles contained in a predetermined mass of exhaust gas and measuring the loss of reflectance, i.e., degree of staining, of this filter relative to the absolute reflectance of the filter when clean or free of stain. The uncertainty of the smoke emission evaluation is estimated to be within ±3 SN (smoke numbers).

1. INTRODUCTION AND DEFINITIONS [Reserved]

2. MEASUREMENT OF SMOKE EMISSIONS

2.1 **Sampling probe for smoke emissions**

a) The probe material with which the exhaust emission sample is in contact shall be stainless steel or any other non-reactive material.

b) If a probe with multiple sampling orifices is used, all sampling orifices shall be of equal diameter. …

EQUIVALENT PROCEDURES

Stainless steel is the preferred probe material but other non-reacting materials may be more suitable under specific circumstances, e.g. engine exhaust temperatures which exceed the physical specification limits of stainless steel. Inconel 625 and Nimonic 75 alloys have previously been accepted as a non-reactive probe material in the context of the regulated species. Other materials may be suitable but need to be approved by the certificating authority.

b) … The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

EXPLANATORY INFORMATION

Smoke particles are submicron in size which, for sampling from gas turbine engines, precludes the need for isokinetic sampling. Never-the-less good practice would suggest sampling as close to isokinetic as possible. Taking an 80 per cent pressure drop at the probe orifices is a reasonable compromise. Further information on probe design is provided within the section on Appendix 3, paragraph 5.1.1.

c) The number of locations sampled shall not be less than 12. [Reserved]

d) The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameters of the exit plane.

EXPLANATORY INFORMATION

The definition of the engine exhaust nozzle is contained in Part 1, Chapter 1, Definitions.

EQUIVALENT PROCEDURE (for mixed flow engine configurations)

For accurate gaseous emissions measurements and representative samples, it is considered best practise to arrange the engine configuration in such a way as to separate the fan and core flows, without affecting the engine performance, and to sample just the core flow. This is equally applicable to smoke emission measurements, however for mixed flow engine designs, the dilution and mixing of bypass air also needs to be taken into account with respect to the exhaust nozzle location. This means that the measured core SN would need to be corrected analytically for dilution and mixing in order to compare against the original visibility criteria.

Currently, Annex 16, Volume II does not contain any method or procedure for these corrections which has led to inconsistent application of the requirements. Where no specific engine data is available, Version 3 of the First Order Approximation (FOA) for estimating Particulate Matter emissions, which contains correlations between SN and non-volatile PM, is provided as a generic dilution correction in the technical procedure below. If it can be shown that an improved correlation is available for a given engine type, or the FOA is developed further, then the improved correlation shall be used with the approval of the certificating authority. No generic mixing correction procedure has yet been identified, and as such, certificating authorities need to address this issue on a project by project basis. Ideally the measured core SN would already meet the SN limit. Where this is not the case, further evidence may be required to inform a technically based engineering judgement as to whether the plume could still considered to be invisible. This could include a detailed traverse at the mixed exhaust nozzle plane in order to perform a contour analysis and determine the level of mixing.

TECHNICAL PROCEDURE

The following procedure is provided as guidance material on how to correct core Smoke Numbers for dilution at a mixed flow engine exhaust nozzle:

Step 1: Convert measured core smoke number to equivalent carbon mass concentration

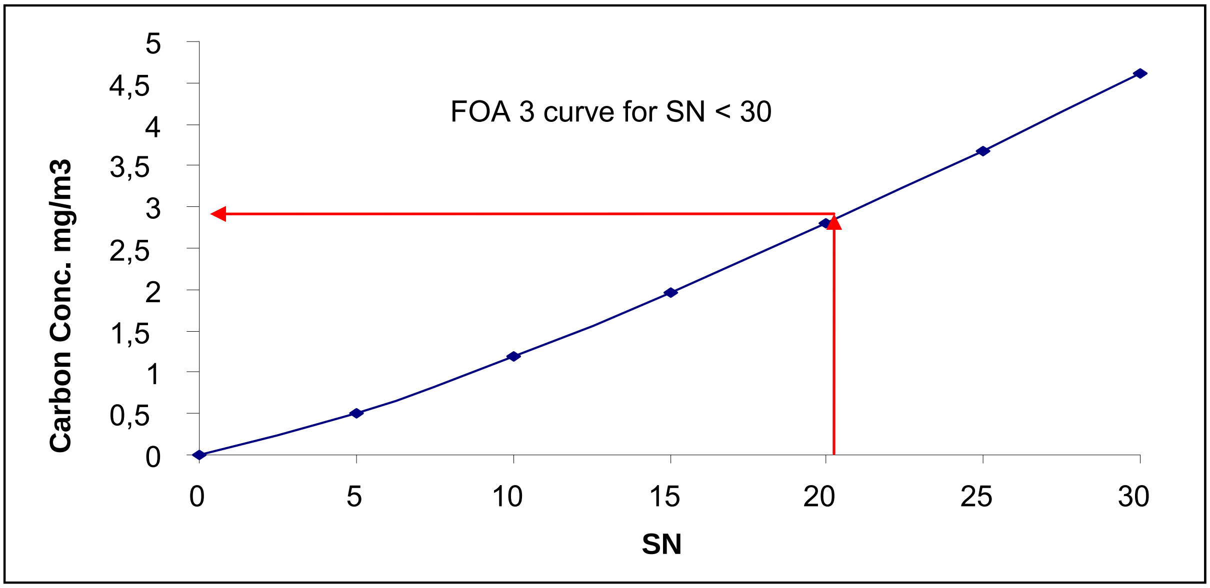


Figure 1: SN plotted against carbon concentration

Based on various research studies, the following FOA carbon correlation equation has been established:

$$CI = 0.0694(SN)^{1.23357} \text{ for } SN < 30$$

Example: From an engine with a maximum measured core Smoke Number of 20, the FOA reference curve provides an equivalent carbon mass concentration of 2.8 mg/m3 at the core exit plane.

Step 2: Adjust carbon mass concentration for mixed stream equivalent

The carbon concentration can now be corrected for the amount of bypass air using the following formulae:

$$\text{Mixed Carbon Mass} = \frac{\text{Core Carbon Mass}}{1 + \text{Bypass Ratio}}$$

Example: Assuming a bypass ratio of 5, the mixed carbon mass concentration is 2.8/(1+5) = 0.47 mg/m^3 at the mixed nozzle exit plane.

Step 3: Convert mixed stream carbon mass back to a smoke number

Using the FOA reference curve, the mixed flow carbon mass (calculated in the previous step) is converted to an equivalent smoke number.

Example: The diluted smoke number, accounting for the fan air using the FOA reference curve, is 4.8 at the mixed nozzle exit plane.

e) The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed thrust setting.

EXPLANATORY INFORMATION

Smoke measurements can be performed by means of a single point probe which is traversed through the sampling plane in sufficient detail to provide a representative sample. This measurement can also be made using a multi-orifice probe which has been demonstrated to provide a representative sample by comparison with those of the single point traverse. Work sponsored by the SAE E-31 Committee has shown that the best agreement between a detailed traverse, used to establish the mean value of smoke emissions in the sampling plane, and a multi-point sampling probe is achieved when this probe's sampling orifices are located on centres of equal area. The most common configuration is that of a cruciform with the individual orifices equally distributed and located on centres of equal area.

2.2 Sampling line for smoke emissions

2.2.2 *Note.— Stainless steel or carbon loaded grounded polytetrafluoroethylene (PTFE) meet these requirements.*

EXPLANATORY INFORMATION

If carbon-loaded grounded polytetrafluoroethylene (PTFE) is used special care must be taken to allow sufficient cooling of the exhaust sample from the probe to the PTFE line to prevent damaging the PTFE line and possibly compromising the sample.

2.3 Smoke analysis system

a) *sample size measurement* [Reserved]

b) *sample flow rate measurement* [Reserved]

c) *filter and holder* [Reserved]

d) *valves* [Reserved]

e) *vacuum pump* [Reserved]

f) *temperature control* [Reserved]

g) If it is desired to draw a higher sample flow rate through the probe than through the filter holder, an optional flow splitter may be located between the probe and valve A (Figure 2-1), to dump excess flow. The dump line shall be as close as possible to probe off-take and shall not affect the ability of the sampling system to maintain the required 80 per cent pressure drop across the probe assembly. The dump flow may also be sent to the CO_2 analyser or complete emissions analysis system.

EXPLANATORY INFORMATION

Achieving an 80 per cent pressure drop across the probe assembly can result in an unacceptably high sample flow rate through the filter holder due to the pressure drop taken across the filter. In these instances, a flow splitter may be required.

h) If a flow splitter is used, a test shall be conducted to demonstrate that the flow splitter does not change the smoke level passing to the filter holder. This may be accomplished by reversing the outlet lines from the flow splitter and showing that, within the accuracy of the method, the smoke level does not change.

EXPLANATORY INFORMATION

Smoke from gas turbine engines, although consisting of sub-micron particles, can be particularly sensitive to flow splitter design or other flow elements in the sampling stream due to inertial separation at very high flow velocities. This test addresses these concerns and ensures that the splitter design does not adversely impact the smoke emissions evaluation.

i) *leak performance* [Reserved]

j) *reflectometer*

EQUIVALENT PROCEDURE

ARP 1179 Rev. C requires the use of a green tristimulus filter to adjust for the effect of various light sources from different reflectometer manufacturers. While this is not a requirement in Annex 16, Volume II, it is considered best practice to follow this approach.

2.4 Fuel specifications [Reserved]

2.5 Smoke measurement procedures

2.5.1 Engine operation [Reserved]

2.5.2 Leakage and cleanliness checks

EXPLANATORY INFORMATION

Leakage checks are to ensure clean air does not leak into the system thereby diluting the sample and lowering the smoke number. Cleanliness checks ensure that the sampling system is acceptably clean and the collecting filter will not be contaminated. If the probe cannot be removed from the sampling stream during engine start-up, the probe and lines should be back pressured with a suitably clean gas, such as dry nitrogen, to minimize contamination problems.

2.5.3 Smoke measurement

EXPLANATORY INFORMATION

It is common practice, while sampling for smoke, to also measure levels of CO_2 as an operational check of the sampling system. The engine fuel-air ratio is calculated from the measured CO_2 and compared to the fuel-air ratio obtained from engine performance data. These should be in agreement within ±10 per cent at engine power above idle and within ±15 per cent at idle.

Paragraphs a) through d) provides for adjusting and setting the sample flow rate through the filter holder. To duplicate the pressure drop through the filter holder during actual sampling conditions a clean filter is clamped into the holder. This filter should be removed and discarded before clamping a clean filter into the holder as described in d).

3. CALCULATION OF SMOKE NUMBER FROM MEASURED DATA

EXPLANATORY INFORMATION

The absolute reflectance of each clean filter should be determined as well as that of the stained filter. Work performed by Dieck, et al, "Aircraft Gas Turbine Smoke Measurement Uncertainty Using the SAE/EPA Method", Journal of Aircraft, Vol. 15, No. 4, April 1978, concluded that "The major instrument-related source of error in SAE/EPA smoke measurement is clean-filter reflectance precision. It is a direct result of the variability in filter reflectance about the average value used".

The backing material should be flat and provide equal pressure across the surface of the filter.

4. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY [Reserved]

**APPENDIX 3. INSTRUMENTATION AND
MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS**

1. INTRODUCTION

EXPLANATORY INFORMATION

The sampling and analysis procedures prescribed in ICAO Annex 16, Volume II, Second Edition, 1993 were adopted from SAE Aerospace Recommended Practice ARP 1256, "Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines". The calculation procedures were derived from ARP 1533 'Procedure for the Analysis and Evaluation of Gaseous Emissions from Aircraft Engines". ARP 1256 and ARP 1533 were developed and are maintained by SAE committee E-31, Aircraft Exhaust Emission Measurement.

2. DEFINITIONS [Reserved]

3. DATA REQUIRED

3.1 Gaseous Emissions

a) Hydrocarbons (HC): a combined estimate of all hydrocarbon compounds present in the exhaust gas.

EXPLANATORY INFORMATION

Gas turbine engine exhaust gases typically contain a variety of hydrocarbon compounds. The specific compounds present and their relative concentrations are usually unknown. Flame Ionization Detectors, used to measure hydrocarbons, do not respond equally to all hydrocarbon compounds. Although this differential hydrocarbon response is to be held within specific bounds, the resulting measurement is an estimate of the hydrocarbon compounds present in the exhaust gas.

3.2 Other information [Reserved]

4. GENERAL ARRANGEMENT OF THE SYSTEM

EXPLANATORY INFORMATION

Water is a major product of combustion. Its removal upstream of the measuring instruments is attractive. Removal would minimize possible interference effects where the instrument responds to the water present as well as to the gas or vapour being measured. It would also prevent or minimize water condensing in the instruments which could cause erratic flow and/or contamination. In the worst case, the instrument would be rendered inoperable until thoroughly cleaned. However, devices which remove water are known to remove hydrocarbons and oxides of nitrogen, and are therefore only permitted for CO and CO_2 measurements. If the sample is dried, an appropriate dry/semi-dry to wet correction must be made.

For most aircraft gas turbine engines, and most engine running modes, supplemental pumps will be needed to meet the probe system pressure drop requirement (80 per cent at the probe entrance orifices), the sample line residence time and pressure drop, and the need to remove excess flow from the sampling system. Any pump used for the purpose of sample transfer must be heated. Usually, because of the sample gas physical properties and the need to maintain temperature and flow control within the Flame Ionization Detector used for hydrocarbon analysis, these instruments utilize internal heated, inert sample transfer pumps. The use of an upstream flow splitter to dump a portion of the sample is also an acceptable procedure to assist in controlling flow to the analytical sampling train.

If loss of hydrocarbons in the sampling system is a concern, the FID can be, when configured with a heated transfer pump, located upstream of the system hot pump as close as physical constraints will allow (e.g. temperature, noise, vibration). The necessity for a dump and/or a hot-sample pump will depend on the ability to meet the sample transfer time and analysis sub-system sample flow rate requirements. This in turn depends on the exhaust sample driving pressure and line losses. Therefore, in general, the size and location of the pumps, and the associated flow control devices, are determined from the particular sampling system configuration.

5. DESCRIPTION OF COMPONENT PARTS

5.1 Sampling system

5.1.1 Sampling probe

a) The probe material with which the exhaust emission sample is in contact shall be stainless steel or any other non-reactive material.

b) If a probe with multiple sample orifices is used, all sampling orifices shall be of equal diameter. …

EQUIVALENT PROCEDURES

Stainless steel is the preferred probe material but other non-reacting materials may be more suitable under specific circumstances, e.g. engine exhaust temperatures which exceed the physical specification limits of stainless steel. Inconel 625 and Nimonic 75 alloys have previously been accepted as a non-reactive probe material in the context of the regulated species. Other materials may be suitable but need to be approved by the certificating authority.

EXPLANATORY INFORMATION

A probe design with multiple orifices (mixing probe) could include either several sampling orifices leading into a single plenum, or several sampling orifices leading into individual sample lines which are mixed external to the probe, as shown in Figure App.3-1. The sampling orifices should be equal in size and located on centres of equal area for all mixing probes. If a multi-armed probe is used, then there should be an equal number of orifices on each arm. Considerations for probe design leading to these criteria can be found in "Gas/Turbine Emission Probe Factors", SAE Aerospace Information Report AIR4068A, 1996.The most common configuration is that of cruciform with individual orifices located on centres of equal area.

b) … The probe design shall be such that at least 80 per cent of the pressure drop through the probe assembly is taken at the orifices.

EXPLANATORY INFORMATION

The pressure drop is needed to isokinetically sample flows at the different orifices. The orifice is supposed to be the minimum area right at the probe entrance. To achieve the pressure drop criterion, there must be a rapid expansion into the sampling tube.

The pressure drop refers to the dynamic head, not the total pressure, and is needed to ensure that each orifice takes a flow rate that is proportional to the dynamic head present at the sampling orifice. Thus, when the samples taken by the individual sampling orifices are mixed together within the probe, the total sample is representative of the mass flux of emissions through the engine exhaust sampling plane.

$$\frac{P_{t0} - p_{s(n^{o}i)}}{P_{t0} - p_{sout}} \rangle\, 0.8 \quad P_{t0} - p_{s(n^{o}i)} \rangle\, 0.8\, P_{t0} - p_{sout}$$

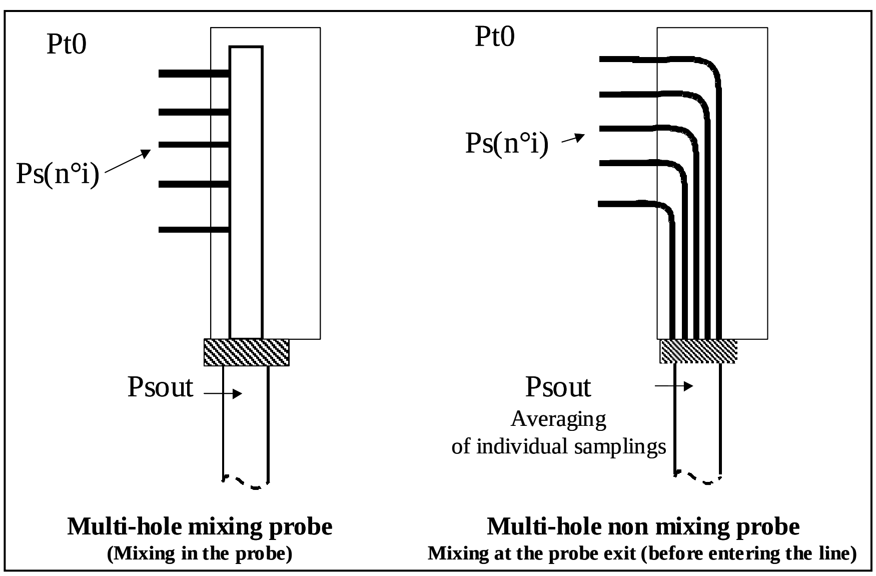


Figure App.3-1. Sampling probe designs

c) The number of locations sampled shall not be less than 12.

EXPLANATORY INFORMATION

While 12 orifices is the minimum number for a sampling rake in Annex 16, Volume II, a more appropriate number would be 20 when validated by means of a detailed traverse.

d) The sampling plane shall be as close to the engine exhaust nozzle exit plane as permitted by considerations of engine performance but in any case shall be within 0.5 nozzle diameter of the exit plane.

EXPLANATORY INFORMATION

Further guidance on the issue of "Exhaust Nozzle" is available under the Definitions in Part 1, Chapter 1.

e) The applicant shall provide evidence to the certificating authority, by means of detailed traverses, that the proposed probe design and position does provide a representative sample for each prescribed thrust setting.

EXPLANATORY INFORMATION

Detailed traverse measurements, although expensive, could be performed with a single hole probe which measures stabilized concentrations at various positions. These individual measurements will then be used to derive average values and demonstrate representative sampling. The carbon balance check is also derived in the same way. The "80 per cent pressure drop" condition which has been introduced in the past to guarantee the sample is representative, is no more justified for the purpose of a single hole probe.

TECHNICAL PROCEDURE

There is no standard definition of a "representative sample" for emissions from aircraft gas turbine engines, nor is there a specification for "detailed traverse". "Representative" and "detailed" are, in this instance, matters of opinion to be negotiated between the manufacturer and the certificating authority. The issue is to do with how much the measured averaged sample can deviate from the true sample mean before it is no longer considered to be representative. The most commonly used definition, arrived at from decades of testing and collaborative analytical exercises by user groups, is 10 per cent for engine modes above idle (i.e., approach, decent, climb and take-off), and ±15 per cent for idle, as per the carbon balance check in section 6.4 of Appendix 3. There is a significant difference however. For the carbon balance check a comparison is made between sets of independently related measured values. With knowledge about the combustion process and the hydrogen to carbon ratio of the fuel used, an estimate can be made from the measured carbon containing species, most of which is CO_2, of the engine average fuel to air ratio. The actual engine fuel to air ratio can be independently arrived at from measured fuel and airflow. These two values can be compared to provide an estimate of how well the exhaust stream was sampled for carbon containing compounds. However, as CO_2 far outweighs the influence of any other carbon bearing species in the calculation of fuel to air ratios, the spatial variability of CO_2 will determine how many sampling points are required and how these sampling points should be distributed. CO_2 has been found to consistently exhibit the least variability of all the species of interest, which include CO, HC,

NO_X and smoke. This suggests that it would be possible to meet the 10 and 15 per cent criteria for carbon balance without having obtained a representative sample, using the same 10 and 15 per cent criteria, of the other species. In other words, obtaining a carbon balance, while a necessary pre-condition for a representative sample, could not be considered to be a sufficient demonstration of representative sampling on its own.

Historically engine manufacturers, or testing agencies, have addressed this problem in different ways. Recognizing that gas turbine engines are predominately axi-symmetric, one acceptable method (for fixed rake designs) has been to sample the exhaust plume, point by point, with a sufficient number of points to be able to estimate, by statistical means, the true engine average species concentration for each of the species of interest. Engine exhaust species seem almost normally (Gaussian) distributed, thus making simple statistical tools acceptable. Using these sampling points, and the measured concentration values for each of the species of interest, contour plots of constant concentration (isopleths) have been analytically generated at each power setting tested. There are a number of computer programs available for workstations or desktop computers to do this. A probe or rake design is then overlaid on the contour plots in order to estimate the average probe/rake values and compare to the estimated true average arrived at from the detailed traverse. If the comparisons match the carbon balance criteria, within 10 per cent for engine powers above idle and ±15 per cent at idle, the probe/rake can be considered to provide representative sampling. This process may have to be repeated several times before an acceptable design is found.

EQUIVALENT PROCEDURE

When applying this analytical technique, for core flow only, multi-orifice rake designs which have proven most robust seem to have four sampling arms spaced 90 degrees apart with sampling orifices located on centres of equal area. The sampling orifices are equally distributed across the sampling arms and the contour analysis will determine the minimum number of sampling ports necessary to yield a representative sample.

A detailed traverse was not required for rotating rake designs as they provide, in normal use, as many or more sampling points than the typical single point traverse thus ensuring a representative sample. However, in order to demonstrate that a fixed rake design is orientated in the right position to collect a representative sample, traverse measurements were necessary. The detail (single point, number of rake orientations, number of different power settings) of traverse measurements may depend on the number of sampling orifices on the rake and existing experience of similar engines or derivatives. These rake design requirements were recognized as being complemented by the system check performed in the carbon balance criteria. Where a sample has low EIs and relatively large "per cent" variations between the detailed traverse and the fixed rake measurements, it could be accepted as representative without having demonstrated NO_X, CO and HC to be within 10 per cent (15 per cent for idle) as long as there is a sufficient large number of orifices and an AFR match within 10 per cent (15 per cent at idle).

All data used in arriving at a probe/rake design should be made available to the certificating authority.

5.1.2 Sampling lines [Reserved]

5.2 HC Analyser [Reserved]

5.3 CO and CO_2 analysers [Reserved]

5.4 NO_X analysers [Reserved]

6. GENERAL TEST PROCEDURES

6.1 Engine operation [Reserved]

6.2 Major instrument calibration [Reserved]

6.3 Operation [Reserved]

6.4 Carbon balance check [Reserved]

7. CALCULATIONS

TECHNICAL PROCEDURE

This technical procedure provides guidance on the processing of measured data from an emissions certification test in the form of a simplified worked example.

Definitions:

Reference engine – For this example, the emissions certification values are calculated based on combustor inlet conditions (T3, P3, and fuel flow) from a validated engine performance model.

Test engine(s) – Recommended practice is to use an engine which conforms to the production build standard. If differences exist, these differences must be documented for approval by the certificating authorities. If any of these non-conformances are predicted to impact engine performance, gaseous emissions or smoke levels, then an explanation and quantification of the impacts will be provided to the certificating authorities for approval. Generally manufacturers will keep deviations from the production standard to a minimum. Measured emissions levels will be corrected to reference engine (production build standard) and standard day conditions.

Detailed traverse – For a new engine type, the next step prior to the actual emission certification test is to conduct a detailed traverse of the engine exhaust to show that a representative sample is being obtained (further guidance in the ETM on detailed traverse see ETM Appendix 3, 5.1.1).

Emissions tests – Emissions are typically measured at more than the four required thrust levels (typically 8-16 conditions) between ground idle and maximum rated thrust.

Instrument calibration curves for the different analyzers may need to be established in order to translate instrument readings to calibrated concentration values. These gas concentrations will be recorded and emission indices will be calculated from that using the equations in 7.1.2 of the Annex 16 Vol. II. The following simple example shows how to derive EI(CO). Assuming the measured values all on a wet basis:

$n/m = H/C = 2$;
$CO = 500\ ppm(v)_{wet} = 0{,}0005$;

$HC = 800\ ppm(v)_{wet} = 0{,}0008$;
$CO_2 = 2{,}25\% = 0{,}0225$;
$NO_2 = 20\ ppm(v)_{wet} = 0{,}00002$;
$h_{amb} = 0{,}0025\ vol_{water}/vol_{dryair}$
$CxHy = CH_4 \rightarrow x=1, y=4$

The equation in 7.1.2 for EI(CO) would then read:

$$EI(CO) = (CO/(CO + CO_2 + HC)) * (10^3 * 28{,}011g / (12{,}011g + n/m* 1{,}008g) * (1 + (0{,}0003 * (P_0/m)))$$

Where:

$(P_0/m) = (2*Z - n/m) = 2*Z – 2$
$Z = \{2 – CO – (2/1 – 4/2*1) * HC + NO2\}/ \{CO + CO_2 + HC\}$
$= 2 – 0{,}0005 – 0 * HC + 0{,}00002 = 1{,}99952$
$(P_0/m) = 1{,}99904$

Hence, from the equation above:

$$EI(CO) = (0{,}0005/0{,}0225+0{,}0005+0{,}0008) * (28011/(12{,}011 + 2{,}016)) * (1 + (0{,}0003*1{,}99904))$$
$$= 0{,}021008 * 1996{,}934483 * 1{,}000056$$
$$= 41{,}98\ g/kg_{fuel}$$

EI(HC) and $EI(NO_X)$ are calculated in a similar manner using the other two equations in 7.1.2. For $EI(NO_X)$ the NO_2/NO converter efficiency must also be taken into account. EIs are calculated for each measurement point (thrust condition) and engine run.

Attachment E of Appendix 3 contains a comprehensive and precise numerical method which is often used by engine manufacturers software programs. Further information is contained in *SAE ARP 1533 Procedure for the Analysis and Evaluation of Gaseous Emissions from Aircraft Engines* which contains two fully worked examples of the Matrix method solving the combustion chemical equation.

To correct these EIs from measured to reference engine and ambient conditions, a curve fitting technique is recommended. One acceptable alternative method of plotting measured test data is to plot the following:

EI(CO) * P3 v. T3

EI(HC) * P3 v. T3

$EI(NO_x)$ * P3 ^-0.5 * exp (19 [h_{mass} – 0.006 34]) v. T3

A best fit of each of the data curves can then be obtained, typically using a polynomial function. In some cases, two curve fit equations are needed, one for low power data and one for high power data. When more than one engine test has been conducted on an engine, data may be plotted for each test run or a single correlation may be used for the multiple runs. However, if multiple engines are tested, a separate set of plots should be made for each test engine.

The procedure for calculating the corrected EI(CO) at values of Fn corresponding to the four LTO operating modes includes the following steps (as shown in Figure A3.1) *[Reserved]*:

1. Use validated engine performance model to determine T3ref, P3ref and reference fuel flow
2. Starting with T3ref, determine EI(CO) * P3 from the EI(CO) * P3 v. T3 curve
3. Divide by the corresponding P3ref to get: Corrected EI(CO) = EI(CO) * P3 / P3ref

Calculation of corrected EI(HC) follows exactly the same process as EI (CO), as does the calculation of corrected EI(NOx) except step 3 involves multiplying by P3ref ^ 0.5 rather than dividing by P3ref.

Once the Corrected EI(CO), EI(HC) and EI(NOx) have been calculated for each operating mode, Dp is calculated using the standard LTO times in mode and corresponding values of reference fuel flow from the validated engine performance model.

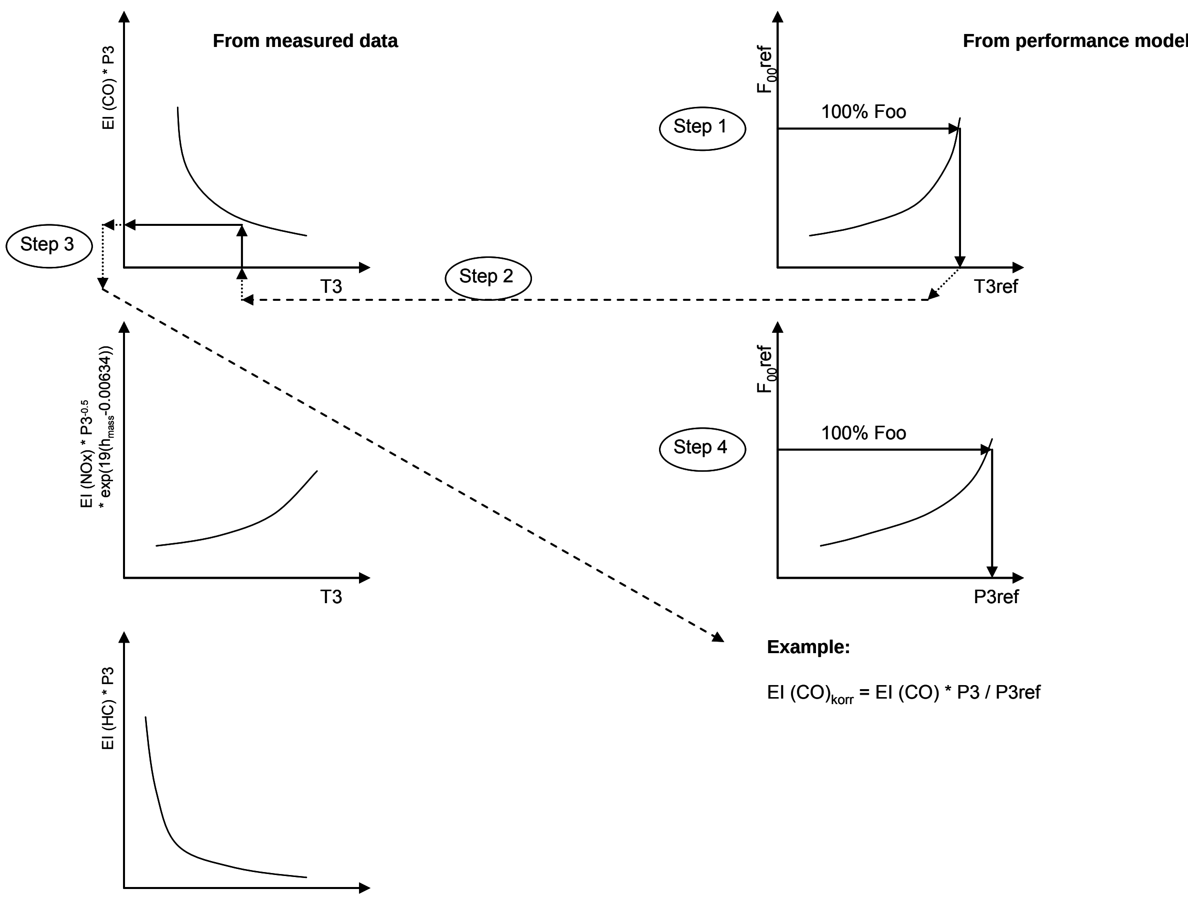


Figure A3.1 – Gaseous Emissions Calculation Procedure

7.1 Gaseous emissions [Reserved]

7.1.1 General [Reserved]

7.1.2 Basic Parameters [Reserved]

7.1.3 Correction of emissions indices to reference conditions [Reserved]

7.2 Control parameter functions [Reserved]

7.3 Exceptions to the proposed procedures [Reserved]

ATTACHMENT A TO APPENDIX 3. SPECIFICATION FOR HC ANALYSER

1. GENERAL

Precautions: The performance specifications indicated are generally for analyser full scale. Errors at part scale may be a significantly greater percentage of reading. The relevance and importance of such increases shall be considered when preparing to make measurements. If better performance is necessary, then appropriate precautions shall be taken.

EXPLANATORY INFORMATION

The performance specifications for these analyzers, given in terms of full scale response, can have a significant and adverse impact on part scale measurements. In extreme instances, concentrations of HC at high power, such as take-off, can differ from concentrations at idle by orders of magnitude. In general it is always good practice to use a multi-range instrument and to adjust ranges such as to keep the measurement in the upper 30 per cent of the instrument response range. Calibrations should be performed on each range used as required.

The instrument to be used shall be such as to maintain the temperature of the detector and sample-handling components at a set point temperature within the range 155°C to 165°C to a stability of ±2°C.

EXPLANATORY INFORMATION

ICAO Annex 16, Volume II previously (Amendment 6 and before) had a set point temperature within the range of 155ºC to 165ºC to a stability of +/- 2°C. This was adopted from SAE ARP1256, "Procedure for the Continuous Sampling and Measurement of Gaseous Emissions From Aircraft Turbine Engines - 1971. ARP1256 specified this range to meet the need for minimising the condensation of hydrocarbons in the instrument and in recognition of the operating characteristics of then commercially available total hydrocarbon analysers (THAs). Since then the ARP has been revised, and now requires a single temperature set point of not less than 160ºC but with no temperature stability requirement. Commercially available THAs have evolved and the more common detector housing temperatures approach 200ºC. This increase in temperature does not effect the emissions certification measurements but does place an unnecessary constraint on the test procedure.

a) *Total range*: 0 to 5 000 ppmC in appropriate ranges.

EXPLANATORY INFORMATION

A total range of 0 to 5,000 ppmC, while appropriate for the engines in use when Annex 16, Volume II was published in 1981, is broader than needed for today's engines where concentrations are much lower. Appropriate instruments should be used to ensure best practice measurements in the upper 30 per cent of the range. Thus an instrument with a range upper limit of 5000ppmC may not be necessary and may, in fact, negatively affect the ability to ensure suitable range span due to instrument design limitations.

b) *Resolution*: better than 0.5 per cent of full scale of range used or 0.5 ppmC, whichever is greater. [Reserved]

c) *Repeatability*: better than ±1 per cent of full scale of range used. or ±0.5 ppmC, whichever is greater. [Reserved]

d) *Stability*: better than ±2 per cent of full scale of range used or ±l.0 ppmC, whichever is greater, in a period of 1 hour.

EXPLANATORY INFORMATION

Stability, taken to be span stability and sometimes referred to as repeatability or reproducibility, is the maximum variation in instrument output over a specified time period and within specified environmental conditions when identical concentration samples, near FSD, are passed through the instrument and after zero corrections have been made. Stability is the sum of time dependent drift, i.e. the change in output under invariant laboratory conditions, and changes in output due to other factors such as environmental temperature and/or variations in FID enclosure temperature. Stability is highly dependent on how, and under what environmental conditions the analyzer is used. As such it is out of their control and they choose to specify a value for time dependent drift along with a range of environmental temperatures, i.e., basically under laboratory conditions. Due to improvement of instruments using solid state electronics the drift specifications from modern THC Analysers quote better drift performance (<1 per cent FS over eight hours in laboratory conditions) than the stability requirements of the standard. Errors associated with this factor are small to negligible. As measurements are not taken under laboratory condition and as changes in environmental conditions are the norm rather than the exception operational procedures, as described in 6.3.2 d) of Appendix 3 are required.

e) *Zero drift*: less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater, in a period of 1 hour. [Reserved]

f) *Noise*: 0.5 Hz and greater, less than ±1 per cent of full scale of range used or ±0.5 ppmC, whichever is greater, in a period of 1 hour.

EXPLANATORY INFORMATION

The FID requires fuel and oxidant gases for operation. The fuel gas is typically either a mixture of hydrogen/nitrogen, or hydrogen/helium. If the noise specification cannot be met, and a hydrogen/nitrogen mixture is being used as the fuel gas, it can be helpful to change to a hydrogen/helium mixture.

g) *Response time*: shall not exceed 10 seconds from inlet of the sample to the analysis system, to the achievement of 90 per cent of the final reading. [Reserved]

h) *Linearity*: response with propane in air shall be linear for each range within ±2 per cent of full scale, otherwise calibration corrections shall be used.[Reserved]

2. SYNERGISTIC EFFECTS

Oxygen response: measure the response with two blends of propane, at approximately 500 ppmC concentration known to a relative accuracy of ±1 per cent, as follows:

1) propane in 10 ±1 per cent O_2, balance N_2

2) propane in 21 ±1 per cent O_2, balance N_2

If R_1 and R_2 are the respective normalized responses then (R_1 - R_2) shall be less than 3 per cent of R_1.

EXPLANATORY INFORMATION

The typical range of O_2 concentrations in the core exhaust gas is 18 per cent at idle to 15 per cent at take-off. The specification for a response of <3 per cent between samples of 10 per cent and 21 per cent is conservative and effectively limits the differential response to <1 per cent over the range of interest. If needed the O_2 response can be minimized by adjusting the FID burner fuel/air ratio.

Differential hydrocarbon response: measure the response with four blends of different hydrocarbons in air, at concentrations of approximately 500 ppmC, known to a relative accuracy of ±1 per cent, as follows:

a) propane in zero air

b) propylene in zero air

c) toluene in zero air

d) n-hexane in zero air.

If R_a, R_b, R_c and R_d are, respectively, the normalized responses (with respect to propane), then $(R_a – R_b)$, $(R_a – R_c)$ and $(R_a – R_d)$ shall each be less than 5 per cent of R_a.

EXPLANATORY INFORMATION

While the FID response is assumed to respond in a manner proportional to carbon number, it does vary somewhat with the particular hydrocarbon or class of hydrocarbons being measured. For example, three molecules of methane (CH4) will not necessarily result in the same instrument response as one molecule of propane (C3H8). Due to this differential response, it is useful to think of the FID as responding to an “effective” carbon number. It is important that the instrument responses are acceptable for all of the hydrocarbons in the engine exhaust. The group of hydrocarbons (propylene, toluene, and n-hexane), with propane as a reference, was chosen to represent, in terms of differential response, the range of hydrocarbons expected in the engine exhaust.

3. OPTIMIZATION OF DETECTOR RESPONSE AND ALIGNMENT

3.1 The manufacturer’s instructions for initial setting up procedures and ancillary services and supplies required shall be implemented, and the instrument allowed to stabilize. All setting adjustments shall involve iterative zero checking, and correction as necessary. Using as sample a mixture of approximately 500 ppmC of propane in air, the response characteristics for variations first in fuel flow and then, near an optimum fuel flow, for variations in dilution air flow to select its optimum shall be determined. The oxygen and differential hydrocarbon responses shall then be determined as indicated above.

EXPLANATORY INFORMATION

The FID detector response and alignment can be optimized by adjusting the FID burner fuel and air flow while sampling a mixture containing approximately 500 ppmC propane. Care should be taken when changing fuel flow that the instrument zero does not shift. If it does, the instrument zero should be reset. Response curves illustrating this process are shown in Figures A3-3 and A3-4, and were taken from SAE ARP1256, "Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines".

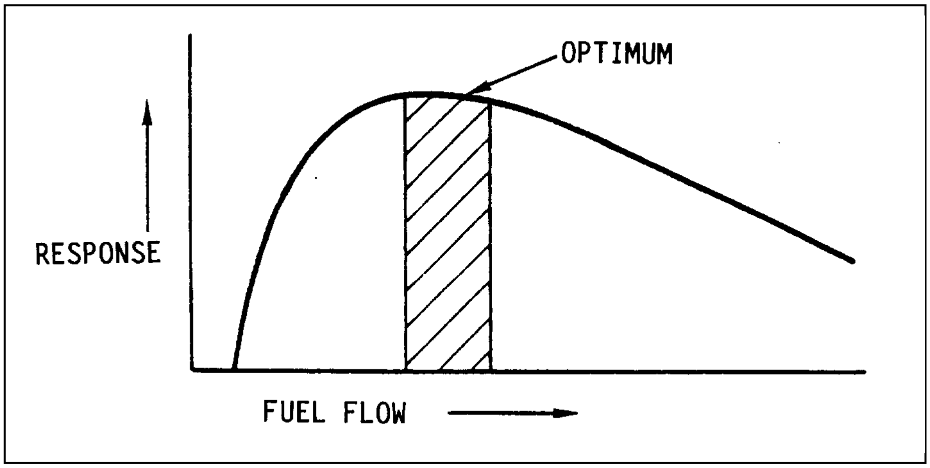


Figure A3-3 Typical Fuel Flow Response Curve

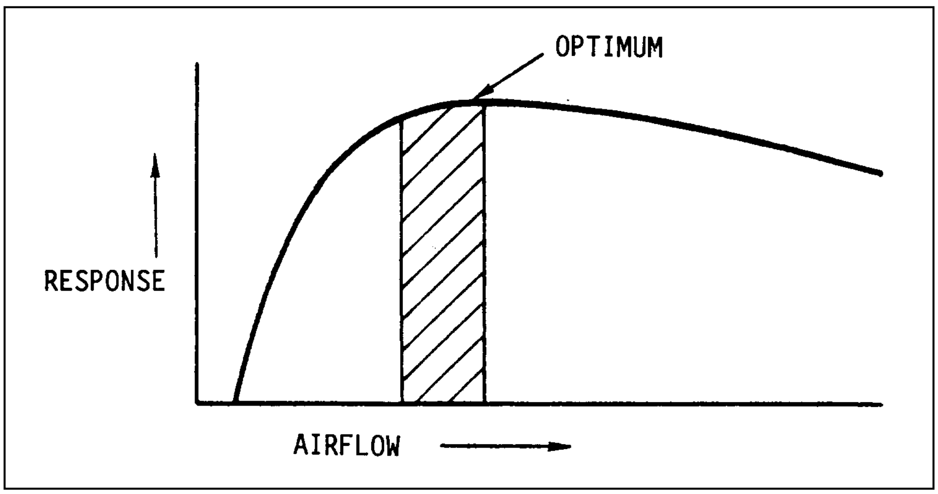


Figure A3-4 Typical Airflow Response Curve

The objective of this procedure is to select operating flow rates which will give near maximum response with least variation for minor fuel flow variations. It may be necessary to repeat this operation in an iterative fashion:

- Adjust the fuel flow to maximize output;
- Adjust zero if necessary;
- Adjust the air flow to maximize output;
- Readjust the fuel flow, if necessary; and
- Repeat until the burner output is optimized.

APPENDIX 4. SPECIFICATION FOR FUEL TO BE USED IN AIRCRAFT TURBINE ENGINE EMISSION TESTING

The fuel used during tests shall meet the specifications of this Appendix 4, unless a deviation and any necessary corrections have been agreed by the certificating authority.

Additives used for the purpose of smoke suppression (such as organo-metallic compounds) shall not be present.

EQUIVALENT PROCEDURE

Appropriate evidence should be provided to the certificating authority to substantiate any deviation from the fuel specification of Appendix 4 as early as possible.

A deviation may be accepted when it can be shown that the locally available fuel does not meet the specification. In such a case, use of the available fuel may be acceptable, subject to the substantiation of corrections to compensate for the effect of the deviation on the measured emissions levels. The measured data should then be corrected to reflect the limiting values of the fuel specification of Appendix 4. Corrections will normally be accepted when the magnitude of the correction to the measured data is small in relation to the margin to the certification limits.

The corrections to the declared emission levels resulting from the deviation in test fuel properties should be based upon engine or rig test data which can be related to the specific combustor type, supported by validated analysis where necessary. The corrections would need to be conservative, particularly when test data is not available for the specific combustor type being certificated. Manufacturers should avoid use of fuels that have been heavily hydro-treated, or produced using synthetic processes.

The deviations from the fuel specification, and the associated corrections, require the agreement of the certificating authority.

APPENDIX 5. INSTRUMENTATION AND MEASUREMENT TECHNIQUES FOR GASEOUS EMISSIONS FROM AFTERBURNING GAS TURBINE ENGINES

[Reserved]

APPENDIX 6. COMPLIANCE PROCEDURES FOR GASEOUS EMISSIONS AND SMOKE

[Reserved]

— — — — — — — —

APPENDIX C

Amendment to Doc 9889

New Chapters on Dispersion Modeling and Ambient Measurements, and Revised Aircraft and Road Vehicle Emissions Inventory Chapters for the Airport Air Quality Guidance Manual

Appendix 1

Airport Air Quality – Chapter 2 Emissions Inventory

Chapter 2
EMISSIONS INVENTORY
Annex 1
AIRCRAFT EMISSIONS

Table of Contents

A1.1 Introduction

A1.1.1 Aircraft main engines may, at times, receive the most amount of attention from those parties concerned with aviation emissions as they can be the dominant airport-related source. This chapter recommends methodologies for the estimation of aircraft engine emissions. Main engines are those used to propel the aircraft forward. Other on-board engines include APU that provide electrical power and pneumatic bleed air when the aircraft is taxiing or parked at the gate and no alternative is available. Fuel venting from aircraft fuel tanks is not allowed and therefore is not addressed as an emission source.

A1.1.2 Main engines are generally classified as either gas turbine turbofan (sometimes referred to as turbojet) and turboprop engines fuelled with aviation kerosene (also referred to as jet fuel) and internal combustion piston engines fuelled with aviation gasoline.

A1.1.4 Main Engine Emissions in the Vicinity of Airports

A1.1.5 Emissions from an individual aircraft main engine combination are primarily a function of three parameters: Time-in-mode (TIM), main engine emission indices (EI), and main engine fuel flows. Aggregate emissions from a fleet serving an airport also include two additional parameters; fleet size/type and number of operations. In the calculation of aircraft emissions at a given airport, the desired accuracy of the emissions inventory will dictate the values and methodology (e.g., Simple, Advanced, or Sophisticated approach) used for determining each of these parameters. While this document tries to simplify the inventory analysis into three approaches, it is generally agreed that the user may at times use a hybrid approach, combining elements from the simple, advanced and sophisticated approaches. However, care should be taken not to use a hybrid approach where all aspects are over-estimated thereby inadvertently assigning a higher burden to aircraft emissions when assessing airport inventories. Consequently, it is recommended that the analyst fully document the analysis methodology including how the guidance document is used. This is discussed further in the "Emissions Calculation Approaches" Section A1.4. The following information provides basic descriptions of each of these parameters:

A1.1.6 Time-in-mode (TIM) is the time period, usually measured in minutes, that the aircraft engines actually spends at an identified power setting; typically pertaining to one of the LTO operating modes of the operational flight cycle.

A1.1.7 Emission Index (EI) and Fuel Flow: An emission index is defined as the mass of pollutant emitted per unit mass of fuel burned for a specified engine. The ICAO Engine Emissions Databank provides the EI for certified engines in units of grams of pollutant per kilogram of fuel (g/kg) for NOx, CO, and HC, as well as the mode-specific fuel flow in units of kilogram per second (kg/s), for the four power settings of the engine emissions certification scheme. Multiplying the mode-specific EI by the TIM-specific fuel flow yields a mode-specific emission rate in units of grams per LTO. For more accurate inventories, adjustments are necessary to these values to take account of, for instance, different power settings, installation effects, etc.

A1.2 Emissions Certification LTO Cycle

A1.2.1 For emissions certification purposes, ICAO has defined a specific reference LTO cycle below a height of 915 meters (3,000 feet) AGL[1], in conjunction with its internationally agreed certification test, measurement procedures and limits (see ICAO Annex 16 Volume II for additional information).

A1.2.2 This cycle consists of four modal phases chosen to represent approach, taxi/idle, take-off and climb and is a much simplified version of the operational flight cycle. An example of its simplification is

[1] AGL: In an emissions inventory study 3000ft Above Ground Level would be referred to the elevation of chosen reference point used in the study. E.g. Elevation AMSL of the ARP.

that it assumes that operation at take-off power abruptly changes to climb power at the end of the take-off roll and that this is maintained unchanged up to 3,000 feet. Whilst not capturing the detail and variations that occur in actual operations, the emissions certification LTO cycle was designed as a reference cycle for the purpose of technology comparison and repeatedly has been reaffirmed as adequate and appropriate for this purpose.

Operating phase	Time-in-mode (minutes)	Thrust setting (percentage of rated thrust)
Approach	4.0	30
Taxi and ground idle (in)	7.0	7
Taxi and ground idle (out)	19.0	7
Take-off	0.7	100
Climb	2.2	85

A1.2.3 This reference emissions LTO cycle is intended to address aircraft operations below the atmospheric mixing height or inversion layer. Whilst the actual mixing height can vary from location to location, on average it extends to a height of approximately 915 meters (3,000 feet), the height used in deriving airborne times-in-mode. Pollutants emitted below the mixing height can potentially have an effect on local air quality concentrations, with those emitted closer to the ground having possibly greater effects on ground level concentrations.[2]

A1.2.4 The certification LTO cycle characteristics selected were derived from surveys in the 1970s. They reflected peak traffic operations (i.e. typical adverse conditions), rather than average LTO operations. The justification for using these for aircraft emission standards was largely based on protecting air quality in and around large metropolitan air terminals during high operational or adverse meteorological conditions.

A1.2.5 It was recognized that even for aircraft of the same type there were large variations in actual operating times and power settings between different international airports, and even at a single airport there could be significant variations day-to-day or throughout a single day. However the use of a fixed LTO cycle provided a constant frame of reference from which differences in engine emissions performance could be compared.

A1.2.6 Thus, the reference emissions LTO cycle is of necessity an artificial model that is subject to many discrepancies when compared to real world conditions at different airports. It was designed as a reference cycle for the purpose of certifying and demonstrating compliance to the emissions standards in effect.

A1.2.7 This LTO cycle, developed for certification purposes, may also be adequate for simple emissions inventory calculations. However, in light of its generic assumptions, use of this cycle typically would not reflect actual emissions. If more precise operations data are available, these data should be used instead to achieve a more accurate inventory.

[2] ICAO recognizes that different States may have different standards or thresholds for designating whether a pollutant as emitted has a local effect. In many cases, this is expressed in terms of a maximum altitude up to which a particular pollutant is emitted. Some States may specify a specific altitude for such purposes. Others may direct that modeling be undertaken to identify the altitude at which pollutants may have local effect in a particular area. This is often referred to as the "mixing height" within the atmospheric "boundary layer." In basic terms, the "mixing height" is the height of the vertical mixing of the lower troposphere. Also in basic terms, the "boundary layer" is that part of the troposphere that is directly influenced by the presence of the earth's surface. States that specify a mixing height is determined for purposes of local air quality assessment typically have accepted models for such analyses and/or specify a default height for the mixing height, such as 3,000 feet.

A1.2.8 As stated elsewhere in the guidance, ICAO aircraft engine emissions standards cover emissions of CO, HC, NOx and smoke. They apply only to subsonic and supersonic aircraft turbojet and turbofan engines of thrust rating greater than or equal to 26.7 kN [Annex 16 Volume II – Aircraft Engine Emissions]. ICAO excluded small turbofan and turbojet engines (thrust rating less than 26.7 kN), turboprop, piston and turboshaft engines, APU and general aviation aircraft engines are omitted from ICAO standards on the grounds of the very large number of models, the uneconomic cost of compliance and small fuel usage compared to commercial jet aircraft.

A1.2.9 Emissions Certification Data

A1.2.10 Emissions certification testing is carried out on uninstalled engines in an instrumented and calibrated static test facility. Engine emissions and performance measurements are made at a large number of power settings (typically greater than ten) covering the whole range from idle to full power and not just at the prescribed four ICAO LTO modes. The measured data are corrected to reference engine performance conditions and reference atmospheric conditions of ISA at sea level and humidity of 0.00634 kg water/kg of air, using well established procedures (See ICAO Annex 16, Volume II for additional information).

A1.2.11 The ICAO engine emissions certification data for CO, HC, and NOx, together with associated fuel flow rates, are reported at a set of four reference power settings defined as "take-off", "climb", "approach", and "taxi/ground idle", respectively and for prescribed times at each of these power settings (i.e., "times-in-mode"). However, smoke emissions are only required to be reported as a maximum value of smoke density, reported as smoke number (SN) for each engine, irrespective of the power setting (although for some certified engines, mode-specific smoke numbers have been reported).

A1.2.12 The emissions certification values previously described are provided in the ICAO Engine Emissions Databank, both as individual engine datasheets and also as a spreadsheet containing the data for all certified engines for which manufacturers have made data available. This databank is publicly available on the worldwide web at www.caa.co.uk/srg/environmental and is periodically updated. An example of an Engine Emissions Datasheet is presented in Appendix A.

A1.3 Operational Flight Cycle Description

A1.3.1 The departure and arrival phases of an actual operational flight cycle for a commercial aircraft are more complex than the four modal phases (i.e., approach, taxi/idle, takeoff, and climb) used for ICAO certification purposes. Actual cycles employ various aircraft engine thrust settings, and the times at those settings are affected by factors such as aircraft type, airport and runway layout characteristics, and local meteorological conditions. However, there are a number of segments that are common to virtually all operational flight cycles. These are depicted in the following diagram (Figure A1-1) and described in the subsequent sections:

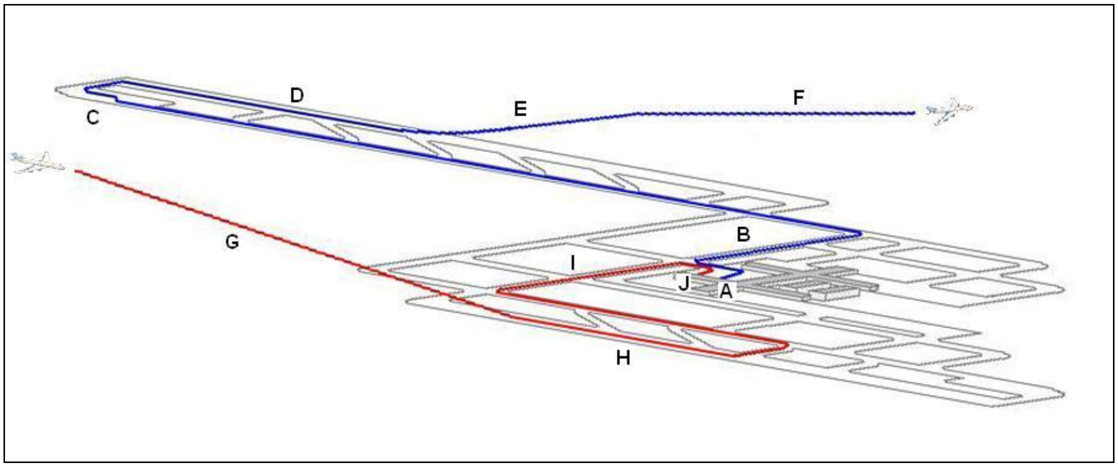


Figure A1-1 Operational Flight Cycle

A1.3.2 Departure

A. Engine start – It is normal to start the main engines prior to, or during, pushback from the aircraft gate/stand. Where aircraft do not require pushback, the main engines are started immediately prior to taxi.

B. Taxi to runway – Aircraft typically taxi out on all engines to the runway or holding area prior to entering the runway; though aircraft may taxi on fewer than all engines under some circumstances. Taxi-out is normally carried out at the idle/taxi power setting apart from brief bursts of power to overcome the initial inertia at the start of taxiing; or if necessary, to negotiate sharp turns.

C. Holding on ground – Where necessary, aircraft may be required to hold in a queue whilst awaiting clearance to enter the runway and taxi to the take-off position. Main engines are normally set to idle thrust with brief bursts of power to move into position.

D. Take-off roll to lift-off – The aircraft is accelerated along the runway to the predetermined rotation speed and the end of the take-off run, with the main engines set to take-off power. Operators rarely use full power for takeoff; rather, a pre-determined thrust setting is set at the beginning of the take-off roll. Operators use either de-rated take-off thrusts or, more often, reduced (e.g., flexible) thrust settings, which are determined by the aircraft actual take-off weight, runway length and prevailing meteorological factors. Throttle handling during the take-off run is sometimes staged in the early part, whereby the throttles are initially set to an intermediate position then a few seconds later are advanced to the predetermined take-off power setting.

E. Initial climb to power cutback – After leaving the ground, the undercarriage (i.e., wheels) of the aircraft is raised and the aircraft climbs at constant speed with the initial take-off power setting until the aircraft reaches the power cutback height (i.e., between 800 and 1,500 feet agl) where the throttles are retarded.

F. Acceleration, clean-up and en-route climb – After the throttle cutback, the aircraft continues to climb at a thrust setting less than that used for take-off with flap/slat retraction following as the aircraft accelerates and reaches cruising altitude.

A1.3.3 Arrival

G. Final approach and flap extension – The stabilized final approach from the Final Approach Fix (FAF) follows a relatively predictable glide slope at low engine thrusts. Thrust settings are increased to counteract the additional drag as flaps and the undercarriage are lowered, whilst speed decreases towards the flare.

H. Flare, touchdown and landing roll – Throttles are normally retarded to idle during the flare and landing roll. This is followed by application of wheel brakes and (where appropriate) reverse thrust to slow down the aircraft on the runway.

I. Taxi from runway to parking stand/gate – Taxi-in from the runway is a similar process to taxi-out to the runway described above; however, operators may shut down one or more engines, as appropriate, during the taxi if the opportunity arises.

J. Engine shutdown – Remaining engines are shut down after the aircraft has stopped taxiing and power is available for onboard aircraft services.

A1.3.4 APU operation, for aircraft equipped with this equipment, is usually confined to periods when the aircraft is taxiing or stationary at the terminal. The APU is typically shut down just after main engine start-up and after landing, the APU is generally started when the aircraft is approaching the terminal area parking position. If one or more main engines are shut down during the taxi, it may also be necessary to start the APU during the taxi-in. A number of airports specify maximum APU running times, principally to limit noise in the terminal area.

A1.3.5 As contained within the following discussion, aircraft activity at an airport is quantified in terms of either LTO cycles or operations. An operation represents either a landing or a takeoff, and two operations can equal one LTO cycle (e.g., taxi out, take-off, a landing and taxi in).

A1.4 Emissions Calculation Approaches

A1.4.1 There are various approaches, or methodologies, to quantify aircraft emissions – each with a degree of accuracy and an inverse degree of uncertainty.

A.1.4.2 This section covers three general approaches to quantifying aircraft engine emissions, with each still having several levels of complexity incorporated. Each approach may incorporate various options for certain parameters and contributing factors, depending in the availability of the data and information.

- <u>Simple Approach</u> is the least complicated approach, requires the minimum amount of data, and provides the highest level of uncertainty often resulting in an over estimate of aircraft emissions. It uses public information and data tables that are very easily available and requires a minimum amount of airport specific information.

  This is the most basic approach for estimating aircraft engine emissions provided in the guidance. The only airport-specific data required are the number of aircraft movements (over a certain period such as a year) and the type of each aircraft involved in each movement (Option A) or some additional basic information on the engine used for each aircraft type (Option B).

  This Simplified Approach should only be used as means of conducting an initial assessment of the aircraft engine emissions at an airport. For most pollutant species, the approach is generally conservative, meaning that the outcome will often overestimate the total level of aircraft engine emissions. However, for some emission species and less common aircraft, the resultant emissions may be underestimated. As such, it is unclear how accurately the Simple Approach accounts for actual aircraft engine emissions at a given airport.

- Advanced Approach reflects an increased level of refinement regarding aircraft types, engine types, EI calculations and TIM. This approach requires specific airport related information or qualified assumptions which are still publicly available but may be more difficult to obtain. It reflects local conditions in incorporating some sort of performance calculation of the aircraft. These improvements result in a more accurate reflection of main engine emissions over the Simple Approach, yet the total emissions are still considered conservative.
- Sophisticated Approach best reflects actual aircraft emissions. It is the most comprehensive approach, requires the maximum amount of data and provides the highest level of certainty. This Sophisticated Approach goes beyond LTO certification data and TIM and utilizes actual engine/aircraft operational performance data. Use of this approach requires a greater knowledge of aircraft and engine operations and in certain instances will require the use of proprietary data or data or models that are normally not available in the public domain and in most instances require the users to perform higher levels of analysis.

A1.4.3 The alternate methodologies afford a progressively higher degree of accuracy and an inverse degree of uncertainty. The purpose and need for quantifying aircraft emissions drive the level of accuracy needed in an inventory, which in turn, determines the appropriate methodology. A secondary factor is data availability. Although an analysis may warrant a high degree of accuracy, it may not be possible for certain elements of the analysis due to lack of available data. ICAO urges that if an emissions inventory involves policies that will affect aircraft operations at a particular airport, then the calculations should be based on the best data available, and the simple approach should not normally be used. Where further information on the aircraft operations at an airport is available, then a more advanced approach is more appropriate.

A1.4.4 It is also important to note that, although at its simplest level it may be possible for individuals to construct an emissions inventory, the advanced and sophisticated methods likely necessitate some form of collaboration with other aviation resources. For example, the identity of actual aircraft and engine types, realistic and accurate times in mode, and actual engine power settings used in the analysis requires data that is often difficult to obtain. In general, the more sophisticated the method, the greater the level of collaboration will be required.

A1.4.5 ICAO stresses the importance for airports and States to use the best data available when assembling an aircraft engine emissions inventory. The ICAO emission inventory methodologies increase in accuracy moving from the Simple to the Advanced and eventually to the Sophisticated Approach. ICAO recommends selecting an approach, or portions thereof, to reflect the desired, or required, fidelity of the results. The air quality practitioner can reference these approaches as ICAO Simple Approach, Advanced Approach, or Sophisticated Approach. It should also be noted that the methods can be combined and that just because a Simple Approach is used for one part of an inventory, does not preclude the use of more precise approaches from being employed for the remaining parts of the emissions inventory.

A1.4.6 The following table provides an overview of the calculation approaches. It lists each of the four primary parameters (e.g., fleet mix, movements, TIM and EI) along with other contributing factors. Also included are explanations of how each of these parameters are determined using the three approaches (e.g., Simple, Advanced, and Sophisticated).

<table>
<tr><th>Key Parameters</th><th colspan="2">Simple Approach</th><th colspan="2">Advanced Approach</th><th>Sophisticated Approach</th></tr>
<tr><td>Fleet (aircraft/engine combinations)</td><td colspan="2">Identification of aircraft group types (e.g. all B737 or all A319/320/321)</td><td colspan="2">Identification of aircraft and representative engine types (e.g. all A320 with 50% V2525 and 50% CFM56-5B5P)</td><td>Actual aircraft type/subtype and engine combinations (by tail number and engine UID or similar)</td></tr>
<tr><td>Movements</td><td colspan="2">Number of aircraft movements by aircraft type (according to look-up table), as defined in "Fleet"</td><td colspan="2">Number of aircraft movements by aircraft-engine combinations as defined in "Fleet"</td><td>Number of aircraft movements by aircraft tail number</td></tr>
<tr><td>Emissions Calculation</td><td>Option A
UNFCC Look-up table (no calculation)</td><td>Option B
Spreadsheet calculation</td><td colspan="2">Performance based calculation, potentially reflecting additional parameters like forward speed, altitude, ambient conditions (model dependent).</td><td>Performance based with actual engine data (P3/T3) and including ambient conditions</td></tr>
<tr><td>Thrust Levels</td><td rowspan="3">Option A
N/A</td><td>Option B
rated thrust</td><td>Option A
Average airport and/or aircraft group specific reduced thrust rate</td><td>Option B
Performance model calculated rated reduced thrust</td><td>Actual air carrier provided thrust</td></tr>
<tr><td>Time in Mode</td><td>Option B
ICAO Certification LTO</td><td>Option A
Modified times in mode (airport specific average or actual for one or several modes)</td><td>Option B
Performance model calculated time in mode.</td><td>Movement based actual values for all modes</td></tr>
<tr><td>Fuel Flow</td><td>Option B
ICAO Certification Databank Values</td><td>Option A
Derived from ICAO EEDB with thrust to fuel flow conversion model</td><td>Option B
Derived from ICAO EEDB with performance model</td><td>Refined values using actual performance and operational data derived from air carrier</td></tr>
<tr><td>Emission Indices</td><td>Option A
UNFCC LTO Emission Mass by Aircraft Type</td><td>Option B
ICAO Certification Databank Values</td><td>Option A
Derived from ICAO EEDB and thrust level through BFFM2 curve fitting method</td><td>Option B
Derived from ICAO EEDB through BFFM2 curve fitting method</td><td>Refined values using actual performance and operational data derived from air carrier.</td></tr>
<tr><td>Start-up Emissions</td><td colspan="2">Not Considered</td><td colspan="2">Consider including - See Sections A1.6.66 – A1.6.75</td><td>Consider including - See Sections A1.6.66 – A1.6.75</td></tr>
<tr><td>Engine deterioration</td><td colspan="2">Do Not Consider - See Sections A1.6.56 – A1.6.65</td><td colspan="2">Do Not Consider – See Sections A1.6.56 – A1.6.65</td><td>Do Not Consider – See Sections A1.6.56 – A1.6.65</td></tr>
</table>

TABLE 1

A1.4.7 When choosing an approach for creating an aircraft emission inventory, a mix of the various approaches and options can be selected. The choice is based upon the availability of data and information, as well as the required accuracy of the inventory. The various elements as listed and described in Annex 1.4.6 are to some degree independent of each other, i.e. not all "Option B" elements necessarily have to go together.

A1.4.8 For logical and consistency reasons, the "Fleet" and "Movements" elements for each approach go together. The Simple Approach Option A as well cannot be mixed with other options or approaches; the same holds true for the Sophisticated Approach. The other elements (Simple Approach Option B and Advanced Options A and B) can be mixed.

A1.4.9 As a prelude to the details involved in each approach, ICAO wishes to establish the general concept within each method. In summary, the inventory starts with an individual aircraft/engine combination(s), and generally applies the operational and emission parameters in a two-step process, as follows:

Step One: Calculate emissions from a single aircraft/engine combination by summing the emissions from all the operating modes which constitutes an LTO cycle, where emissions from a single mode could be expressed as:

Modal emissions for an aircraft/engine combination = TIM x fuel used (at the appropriate power) x EI (at the appropriate power) x number of engines

The emissions for the single LTO operational flight cycle are then a summation of the individual parts of the cycle. In more sophisticated methods, EI and fuel flows may not be constant throughout the time in mode.

Step Two: Calculate total emissions by summing over the entire range of aircraft/engine combinations and number of LTO cycles for the period required.

A1.5 Aircraft Fleet and Movements

A1.5.1 Aircraft fleet is a generic description to describe the various aircraft and engine combinations that serve an airport. In its simplest form, the aircraft fleet can be generally characterised according to descriptors such as, for example, heavy, large, small, turboprop, and piston. For aircraft emissions inventory purposes, however, it is typically necessary to identify fleets more accurately (for example, by aircraft type).

A1.5.2 Aircraft can be generically labelled according to manufacturer and model. For example, “A320” is an Airbus model 320 or a “B737” represents the Boeing 737, though it should be noted that a generic aircraft type may contain significant variations in engine technology and widely differing emissions characteristics between different types and their engine fits.

A1.5.3 A more descriptive labelling for an aircraft type would also include the series number for each model, such as B747-400 for a 400 series Boeing 747 aircraft. This helps to establish the size and technology used in the aircraft engine and is necessary for a more accurate emissions inventory.

A1.5.4 Finally, the most accurate representation of aircraft is to identify the aircraft model, and series along with the actual engines fitted on the aircraft and modifications that affect its emissions performance (e.g., B777-200IGW with GE90-85B engines with DAC II combustors). As the aircraft itself does not produce emissions, having detailed information on engines installed on the aircraft fleet is an essential component of an accurate emissions inventory.

A1.5.6 Simple Aircraft Fleet

A1.5.7 For the Simple Approach, the two primary elements of the aircraft fleet (e.g., aircraft and engine types) have been simplified in a list of the types of aircraft for which pre-calculated emission data is provided. For each aircraft, the engine type has been assumed to be the most common type of engine in operation internationally for that aircraft type[3], and emissions from that engine type are reflected in the associated emission factors. Appendix B contains Table B-1 which lists 52 aircraft and provides emission data for each of their engine types.[4]

A1.5.8 If the fleet servicing an airport includes aircraft that are not contained in Table B-1, then Table B-3 should be used to determine an appropriate generic aircraft. (Refer to the column headed "IATA aircraft in group" to locate the aircraft type shown in the column headed "Generic Aircraft Type".)

A1.5.9 If an aircraft is not contained in either Table B-1 or B-3, then it is recommended to use supplementary information such as weight, number of engines, size category, range, etc. to identify a suitable equivalent aircraft that is in Table B-1 or B-3, recognising that this will introduce additional assumptions that may affect the accuracy of any result. In the case of an airport primarily served by regional jets, business jets and/or turboprops, it is unlikely that the range of aircraft will yield a reliable result. In these cases, a more advanced method is recommended.

A1.5.10 Simple Aircraft Movements

A1.5.11 For the Simple Approach, it is necessary to know (or to have an estimate of) the number of aircraft movements or operations (e.g., LTO) and type of aircraft at an airport over a specified period (e.g. hour, day, month, or year).

A1.5.12 Most airports levy user charges for provision of facilities and services typically collected as a landing fee. In these cases airport operators have accurate records of landing movements; including the number of landings and the type of aircraft. Some airports also record the number of take-offs, although the landing records usually provide more reliable data. For this reason, at larger airports, published data on the annual aircraft movements is often available.

A1.5.13 An LTO cycle contains one landing and one take-off, and so the number of landings and takeoffs at an airport should be equal. The total number of either landings or takeoffs may be treated as the number of LTO. Any difference in the number of landings and the number of take-offs will usually indicate an error in the records; if there is no explanation for this discrepancy, then the greater number should be used.

A1.5.14 If no data is available, it will be necessary to conduct a survey of the number of aircraft movements and the types of aircraft over a short- or medium-term period (e.g. one to six months), noting that there are normally seasonal differences in the number of movements at most airports.

---

[3] As of 30 July 2004 emissions data for the B747-300 is based on proportioned emissions for the two most common engine types.

[4] CAEP developed this data at the request of the UNFCCC in connection with UNFCCC guidelines for national greenhouse gas inventories, which are used for global emissions issues rather than local air quality. It therefore includes data for greenhouse gas emissions that are not relevant to local air quality. These may be disregarded for purposes of inventories assembled for local air quality assessments (though some locations may wish to inventory CO_2 emissions for other purposes). The data included in this document was current at the time of writing. The UNFCCC will provide updates to this table on an on-going basis and the most current table should be used whenever possible [www.ipcc-nggip.igs.or.jp]. If using new data from the UNFCCC website, CH4 and NMVOC data will require summing in order to obtain a value for HC. Since the UNFCCC's main focus was on greenhouse gas emissions over the entire course of flight, the data for LTO emissions is based on ICAO certification standards, and therefore will not accurately reflect actual emissions in an operating setting. In most cases, use of the refinements discussed in the Advanced and Sophisticated Approaches will help to achieve a more accurate inventory for the relevant pollutants.

A1.5.15 Advanced Aircraft Fleet

A1.5.16 Like the Simple Approach, the first step of the Advanced Approach is to quantify the aircraft operations or LTO by aircraft type and specific to the airport. Typically, this information can be obtained directly from airport records, thereby reflecting the most accurate form of this information. However, because no database is entirely accurate and changes due to aircraft engine fits, temporary intermixes, and other considerations over time can introduce inaccuracy, it is important to gather as much information as close to the source of the operation as is possible. If access to this information is not possible, then national traffic statistics can be accessed if available. Additional sources of data include air navigation service providers such as EUROCONTROL and the U.S. FAA, the internet and the other sources described in the paragraphs below. .

A1.5.17 The Advanced Approach then tries to match the various aircraft types operating at the study airport with the engines that are fitted to them. Airports typically have lists with aircraft type/engine combinations obtained from the carriers that service the airport. However, if this information is unavailable, States have access to several publicly available databases that enable the matching of aircraft types with specific engines. Annex 1 Appendix C describes these important databases that can assist practitioners in identifying the aircraft/engine combinations that characterize fleet mix at a particular airport.

A1.5.18 Other sources of information include the International Official Airline Guide (IOAG) Database which contains data that identifies the type of aircraft, carrier, and frequency of scheduled flights. In addition, the IOAG lists scheduled passenger flights by participating airlines, which are updated on a monthly basis. IOAG provides the main components in determining the fleet mix at a specific airport such as airport, aircraft type, carrier, and frequency of aircraft arrivals and departures. However, the IOAG does not include unscheduled and charter flights, or general aviation flights including business jets. The IOAG covers the flights of all U.S. scheduled airlines and the majority of scheduled worldwide airlines. Specifically, Appendix C provides a description of the useful fields contained in the IOAG database. The most important IOAG airport-specific parameters are the flight number, aircraft type, carrier, and schedule when determining the number of operations at a specific airport.

A1.5.19 BACK's World Fleet Registration Database (BACK) contains additional airline fleet information such as all worldwide commercial aircraft currently in use and other various aircraft parameters (see Appendix C for a list of useful fields). For emissions inventory purposes, the most important parameters from the BACK database (or other similar databases) are the aircraft identifiers, tail number, engine model, number of engines, and aircraft type.

A1.5.20 Bucher & Company's JP Airline-Fleets International Database (JPFleets) is another publicly available database that provides aircraft type/engine combinations for major commercial airlines worldwide (see Appendix C for a list of useful data fields).

A1.5.21 Airline Service Quality Performance (ASQP) Database is available from the U.S. Department of Transportation's (U.S. DOT) Bureau of Transportation Statistics (BTS). This database consists of performance and flight data for approximately 20 of the largest U.S. carriers. Appendix C lists the useful fields in the ASQP database. The practitioner should note the ASQP database provides good coverage for the fleet flying in the U.S. and their associated markets abroad.

A1.5.22 Depending upon the reasons for assembling an emissions inventory, a different method of assigning engines to aircraft can be used. One approach is to identify the specific engines used for the aircraft operations. This is achieved by collecting aircraft type information, scheduled flight numbers, and arrival/departure data for a specific airport (e.g., using IOAG), then finding the specific engine types assigned to the identified aircraft using the available databases described above. If this degree of accuracy is not necessary, then an alternative approach can be used to estimate the engine.

A1.5.23 This alternative is based upon the popularity of engines within the worldwide fleet. If the data available does not allow the identification of specific aircraft-engine combinations at a particular airport, these might be estimated. One way of doing this is to extrapolate the information on aircraft-engine combinations from a larger fleet database, such as a worldwide fleet database. For example, if the reference database shows that X percent of the B777 in the worldwide fleet have Y engines, and then it might be assumed for purposes of an airport inventory that X percent of the B777 that operate into that airport have Y engines. States should be aware that a single aircraft type may be fitted with more than one type or subtype of engine, which in turn can have differing emissions characteristics, in an airline's worldwide inventory. For these cases, databases such as BACK, JPFleets, and others can be used to develop distributions of engines based on reported airline and aircraft categories.

A1.5.24 It should be remembered that no database is entirely accurate, and changes due to aircraft engine fits, temporary intermixes, cross-referencing between databases, and other considerations over time can introduce even greater levels of inaccuracy. It is therefore important to gather as much information as close to the source of the operation as is possible in order to minimise uncertainties.

A1.5.25 Advanced Aircraft Movements

A1.5.26 The requirements for aircraft movements needed for the Advanced Approach is nearly identical to the Simple Approach: it is necessary to know the number of aircraft movements or operations by type of aircraft and engine for the advanced approach. When the emissions for the single LTO are calculated for each aircraft/engine combination using the above inputs and equations, the total emissions are calculated by multiplying the single LTO emissions for each aircraft/engine by the corresponding number of movements and summing over the entire range of aircraft/engine combinations and movements for the period required.

A1.5.27 Sophisticated Aircraft Fleet and Movements

A.1.5.28 In the sophisticated approach it is assumed that the modeller has the actual and accurate information on aircraft type and subtype, number and correct engine name and designation for every single movement available. The match between aircraft and engine is through the aircraft registration number in connection with the ICAO or similar engine UID (unique identification number).

A.1.5.29 The total of the movements is derived from the actual movement information for each single aircraft serving the particular airport. Every movement (landing or take-off) is logged by the aircraft's registration number in order to provide the detailed engine information. So the number of movements for a specific aircraft type might include various numbers of this type but by varying aircraft registrations numbers.

A1.6 Aircraft Main Engine Emission Calculations

A1.6.1 Fuel Flow and Emissions Indices

A1.6.2 Aircraft engines with rated power greater than 26.7 kN are emissions-certified by ICAO for emissions of NOx, CO, and HC and maximum SN, based upon the standardised LTO cycle as set out in ICAO Annex 16, Volume II and published originally in Document 9646-AN/943 (1995) and website amendments. ICAO provides the emissions certification data on the worldwide web at www.caa.co.uk. Updates to the Aircraft Engine Emissions Databank are made as new engines are certified. An example of the ICAO Engine Emissions Databank can be found in Appendix A.

A1.6.3 When ICAO engine data are used to calculate aircraft emissions, it is important to select the pollutant measured average value and not the pollutant characteristic level, which also is reported in the

ICAO databank. The characteristic level of a gaseous pollutant or smoke is derived for certification purposes and contains statistical coefficients corresponding to the number of engines tested.

A1.6.4 For the vast majority of commercial aircraft engines operated at major airports, fuel flow and EI values are reported in the ICAO Aircraft Engine Emissions Databank, at the four certification thrust settings. Aircraft engine EI are reported in grams of pollutant per kilogram of fuel consumed (g/kg) and the fuel flow rates for each mode are reported in kilograms per second (kg/s). The reported EI and fuel flow values are recommended by ICAO to be used to calculate emissions from main aircraft engines.

A1.6.5 There are other databases available that address EI and fuel flow information for aircraft engines that are not certified nor regulated by ICAO. The following are two of the primary non-ICAO databases.

A1.6.6 The Swedish Defence Research Agency (FOI) is the keeper of a database of EI for turboprop engines supplied by the manufacturers for the purposes of developing emissions inventories. Although the database is publicly available only through FOI, International Coordinating Council of Aerospace Industries Associations (ICCAIA) closely monitors who requests the use of the database to ensure the data is not misused. The FOI database is not endorsed by ICAO because the data are not certified and may have inaccuracies resulting primarily from the unregulated test methodologies. There is also a significant issue of an appropriate idle setting for turboprops. Therefore, whilst this data is not ICAO-certified aircraft engine emission data, this information is included in this guidance document recognizing that the FOI turboprop database may assist airports in conducting emission inventories. Currently, documentation of how the EI were derived and the types of turboprop engines is unavailable. Information about turboprop engines, suggested TIM and how to obtain the data from FOI can be found at http://www.foi.se/FOI/templates/Page____7070.aspx

A1.6.7 Switzerland's Federal Office of Civil Aviation (FOCA) has developed a methodology and a measurement system to obtain emissions data from piston-powered aircraft and helicopters. For these engine types, there is no requirement for emissions certification; hence the FOCA data is one of the few sources of data available for conducting emission inventories with respect to aircraft with these engines. However, the FOCA data has not been corroborated by ICAO, and is not endorsed by ICAO. Therefore, whilst this data is not ICAO-certified aircraft engine emission data, this information is included in this guidance document recognizing that FOCA data may assist airports in conducting emission inventories for certain aircraft for which they otherwise might not have any data sources. The reader is referred to FOCA website to obtain documentation of the emissions measurement system, the consistent measurement methodology, recommendations for the use of their data to conduct simple emission inventories using suggested TIM. All material is openly available for download at www.bazl.admin.ch → for specialists → environment → aircraft engine emissions.

A1.6.8 Emission Calculations Simple Approach (A)

A1.6.9 Emissions Indices

A1.6.10 In the Simple Approach (Option A), the EI is replaced with an emissions factor (EF)5 and Table B-1 in Appendix B provides these emissions factors for five pollutant species for each of the listed aircraft.

A1.6.11 The emissions factor is provided in terms of kg of each emission species per LTO cycle per aircraft. These have been calculated based on the representative engine type for each generic aircraft type

[5] EI = Emission Index, expressed as g pollutant per kg fuel;
EF = Emission Factor, expressed as mass of pollutant per specified unit (e.g. aircraft)

and using ICAO TIM, thrust settings and other basic assumptions. Other assumptions are described in the notes in Table B-1 in Appendix B.

A1.6.12 Emissions Calculation

A1.6.13 For NOx, HC, CO, SO2 and CO2 there is a standard method for calculating aircraft engine emissions using the Simple Approach (Option A). For each aircraft type, multiply the number of LTO cycles of that aircraft (over the assessment period) by the emissions factor in Table B-1 for each of the pollutant species and then add up the values for all the aircraft to get the amount of total emissions (in kg) for each pollutant. See the following generic equation:

Emission of Species X =	Σ	([Number of LTO cycles) x	(Emissions Factor)	Eq. A1-1
(in kg)	All Aircraft	of Aircraft Y	for Species X	

A1.6.14 Notably, this equation does not account for specific engine types, operational modes or TIM as it assumes that the conditions under study are the same or similar to the default data being used.

A1.6.15 If required for the inventory, a similar process is used for fuel consumption over the period under consideration using fuel consumption data in Table B-1:

Fuel consumption =	Σ	[Number of LTO cycles] x [Fuel Consumption]	Eq. A1-2
(in kg)	All Aircraft	of Aircraft Y	

A1.6.16 There is no provision for the calculation of PM emissions in the Simple Approach (Option A).

A1.6.17 Emission Calculation Simple Approach (B)

A1.6.18 Aircraft Time-in-mode

A1.6.19 As discussed previously, the reference TIM used as part of the ICAO engine emissions certification process (and contained in the ICAO Aircraft Engine Emissions Databank) are only appropriate for the engine certification process, and are not representative of actual TIM aircraft spend in real world operations (see Annex A1.2.1 through A1.2.8). Nonetheless, the ICAO default TIM can provide a conservative estimate of aircraft emissions at an airport when airport-specific taxi/ground idle TIM data or refined methods of estimating takeoff, climb, and approach times are not available. Sensitivity analyses conducted by CAEP determined that conducting an aircraft emissions inventory using the ICAO certification TIM (as well as the fuel flow and EI) normally yields an overestimation of total aircraft emissions across the entire LTO cycle.

A1.6.20 While ICAO default TIM are applicable primarily to regulated engines, there may other default times in mode be available for other engine types (i.e. unregulated turbofan engines, turboprop engines, piston engines or helicopters). Sources for such information could include national aviation or environmental authorities.

A1.6.21 Emissions Calculation Methodology for NOx, CO, and HC

A1.6.22 Identification of the aircraft type will enable the determination of the number of engines and the appropriate engine models. In turn, the engine model will determine the proper EI to calculate aircraft emissions.

A1.6.23 To determine the NOx, CO, or HC emissions for a unique aircraft/engine combination, the following formula may be used. This method is repeated for each aircraft/engine type representing each TIM to establish a complete aircraft emissions inventory.

$$E_{i\,j} = \sum (TIM_{jk} * 60) * (FF_{jk}) * (EI_{jk}) * (N_{ej}) \qquad \text{Eq. A1-3}$$

where:

Eij = Total emissions of pollutant i (e.g., NOx, CO, or HC), in grams, produced by aircraft type j for one LTO cycle

Eijk = The emission index for pollutant i (e.g., NOx, CO, or HC), in grams per pollutant per kilogram of fuel (g/kg of fuel), in mode k (e.g., takeoff, climb out, idle and approach) for each engine used on aircraft type j

FFjk = Fuel flow for mode k (e.g., takeoff, climb out, idle and approach), in kilograms per second (kg/s), for each engine used on aircraft type j

TIMjk = Time-in-mode for mode k (e.g., idle, approach, climb out, and takeoff), in minutes, for aircraft type j

Nej = Number of engines used on aircraft type j

A1.6.24 If the actual measured TIM for one or more of the operating modes exists and is used, then the different flight phases have to be calculated separately and the total emissions for each species have to be summed to give the total emissions for each aircraft/engine type.

A1.6.25 ICAO does not have emissions certification standards for SOx. However, SOx emissions are a function of the quantity of sulphur in the fuel. The U.S. EPA conducted a survey of sulphur content for commercial aviation jet fuel, which resulted in a U.S. average of 1 gram per 1,000 grams of fuel consumed (EISOx = 1 g/kg of fuel). This average should not be relied upon where validated data is needed, but can be used to perform an emissions inventory of SOx emissions using the following equation:

$$E_k = \sum (TIM_k * 60) * (Er_k) * (N_{ek}) \qquad \text{Eq. A1-4}$$

where:

Ek = Total emissions of SOx, in grams, produced by aircraft type k for one LTO cycle

Nek = Number of engines used on aircraft type k

Erk = 1 * (FFk)

where:

Erk = emission rate of total Sox in units of grams of Sox emitted per second per operational mode for aircraft k

FFk = the reported fuel flow by mode in kilograms per second (kg/s) per operational mode for each engine used on the aircraft type k.

A1.6.26 ICAO does not have emissions certification standards for PM emissions. However, CAEP has developed and approved the use of an interim First Order Approximation (FOA) method to estimate total PM emissions from certified aircraft engines. At the time of this document, FOA version 3 is the most up-to-date and is provided in Appendix D of this section. FOA3 provides expressions of volatile PM from fuel organics and sulphur content, as well as a relationship between SN and non-volatile PM mass. CAEP is committed to continually updating the interim FOA methodology as data and scientific advancements become available, until such time as it can be replaced by fully validated and verified measurement data.

The FOA methodology is to be used for emissions inventory purposes only within the vicinity of airports. The FOA methodology should not be relied upon where accurate, validated data is required.

A1.6.27 Emission Calculation Advanced Approach (Options A and B)

A1.6.28 The advanced emission calculation methods make use of performance models that take into account or model ambient and specific aircraft related operational information. As such, a number of additional information is needed that could be obtained more easily by the modeller from public sources. Such information can include the following: aircraft information (take-off mass, actual engine), airport information (airfield elevation, runway usage length), ambient information (wind speed and direction, turbulence, pressure, temperature, humidity) and operational information (destination, stand, runway, departure route, approach route and glide slope, APU usage). The actually needed information depends on the model used and may vary, also refer to Table 1 for additional guidance on what parameters to use..

A1.6.29 Thrust Levels

A1.6.30 While the certification LTO-cycle suggests specific thrust settings for each mode, any operational LTO-cycle may have different modes with more individual power settings (cf. A1.3). Specifically, take-off thrust is often less than the certification 100% for performance and cost-efficiency reasons. Aircraft are more and more operated using flexible thrust rates, sometimes in combination with derated thrust options. This could apply to the take-off phase of a flight as well as to other flight phases in the landing and take-off cycle.

A1.6.31 As an option A, an airport average and/or aircraft group specific reduced thrust level may be available for primarily the take-off phase, but may also be available for other modes. Such information could stem from empirical data, for example, from one aircraft operator, and be extrapolated over the total of the operations.

A1.6.32 In option B, a dedicated aircraft performance model should be utilised that gives an operational thrust level using additional, publicly available parameters unique to the model. The thrust level could be modelled for take-off only or for all modes in the LTO-cycle.

A1.6.33 Time in Mode

A1.6.34 As an option A, airports are encouraged to take measurements of the typical taxi times unique to the airport's taxiway structure for both taxi-in from runway to the terminal and vice versa for taxi-out times, including possible queuing times at departure runways. Using the measured taxi time values for the study airport can better reflect emissions for the taxi/idle mode of the LTO cycle. Such data could be obtained from e.g. touch-down, on-block, off-block and take-off times for either all possible stand/runway combinations or as an airport default.

A1.6.35 As an option B, times in mode could also be modelled for other than just the taxi mode. This option would most likely include an aircraft performance modelling approach, giving aircraft group or even aircraft type individual times in mode for those modes considered in the approach (e.g. more than just the 4 ICAO certification modes).

A1.6.36 Fuel Flow

A1.6.37 For Option A, a relationship has been developed that uses the certification fuel flow and thrust data from the ICAO Engine Emissions Databank to determine fuel flow at any thrust level desired between 60% and 100%. Note. The thrust levels are % of rated output thrust and represent the thrust selected by the pilot. They do not represent the actual thrust delivered by the engine (corrected net thrust). This methodology allows for accurate calculation of fuel flow at reduced take-off thrust levels which in some instances could be as low as 60% of rated thrust. From this fuel flow, corresponding emissions indices can be calculated using the BFFM2 curve fitting methodology. A twin quadratic methodology has been developed, and it is described below;

A1.6.38 The Twin Quadratic method comprises calculation of fuel flow vs thrust, for thrusts above 60% maximum rated thrust. The fuel flow and thrust data required to define the two curves is available in the ICAO Engine Emissions databank for certificated engines. The methodology is as follows:

60% to 85% thrust:	defined by a quadratic equation based on the 7%, 30% and 85% thrust and associated fuel flow points
85% to 100% thrust:	defined by a quadratic equation based on the 30%, 85% and 100% thrust and associated fuel flow points

These two quadratic equations are uniquely defined by their 3 points and meet at 85% thrust. The slopes of the two curves at 85% thrust may be different, (the “kink” shown diagrammatically in Figure A1-2 below).

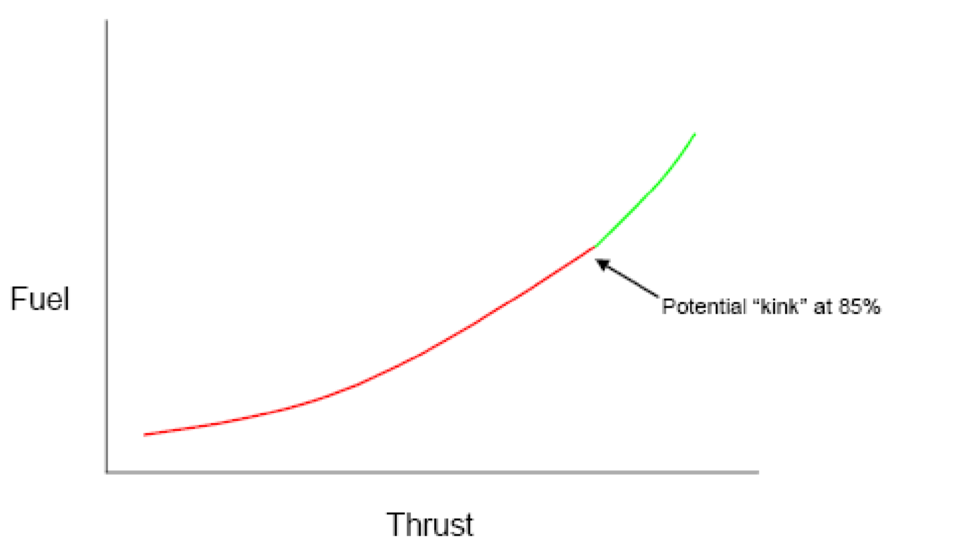


Figure A1-2 Diagrammatic illustration of twin quadratic curve fit

A1.6.39 A quadratic equation to fit through three points on the non-dimensionalised fuel flow versus thrust curve has the following parameters:

X = (thrust)/(maximum rated thrust), Quadratic defined by values X1, X2, X3

Y = (fuel flow)/(fuel flow @ maximum rated thrust), values Y1, Y2, Y3

Giving

$$\mathbf{Y = AX^2 + BX + C}$$

With three known points

$$Y1 = AX1^2 + BX1 + C$$
$$Y2 = AX2^2 + BX2 + C$$
$$Y3 = AX3^2 + BX3 + C$$

Allowing solution for A, B and C as :

$$A = (Y3-Y1)/((X3-X1)*(X1-X2)) – (Y3-Y2)/((X3-X2)*(X1-X2))$$
$$B = (Y3-Y1)/(X3-X1) – A*(X3+X1)$$
$$C = Y3 – A*X3^2 - B*X3$$

A,B and C vary for different engine UIDs

For selected thrusts between 85% and 100% rated thrust:

Known ICAO Engine Emissions Databank points for the engine UID at 30%, 85% and 100% are used to derive A, B and C as above**.**

These are then used in the generic quadratic equation

$$Y = AX^2 + BX + C$$

Where X is the (selected thrust)/(maximum rated thrust)
To give Y (= (desired fuel flow)/(fuel flow at maximum rated thrust)) at the selected thrust.

Fuel flow at the selected thrust is obtained but multiplying Y by the ICAO Engine Emissions Databank fuel flow at maximum rated thrust

The Upper Quadratic curve is applied between 85% and 100% rated thrust only

For selected thrusts between 60% and 85% rated thrust.

Known databank points for the engine UID at 7%, 30% and 85% are used to derive A, B and C as above**.** These are then used in the generic quadratic equation

$$Y = AX^2 + BX + C$$

Where X is the (selected thrust)/(max rated thrust)

To give Y (= (fuel flow)/(fuel flow at maximum rated thrust)) at the selected thrust.

Fuel flow at the selected thrust is obtained by multiplying Y by the ICAO Engine Emissions Databank fuel flow at maximum rated thrust

The Lower Quadratic curve is applied between 60% and 85% rated thrust only

Example calculation for UID 8RR044, Rolls-Royce Trent 553-61:

1) Determination of quadratic curve between 85% and 100% rated thrust

X1 = 0.30
X2 = 0.85
X3 = 1.00

With ICAO Engine Emissions Databank fuel flows:

Y1 = 0.2844
Y2 = 0.8199
Y3 = 1.0000

→ A = 0.3242
→ B = 0.6009
→ C = 0.07491
→ $Y = 0.3242\ X^2 + 0.6009\ X + 0.0749$ (1)

2) Determination of quadratic curve between 60% and 85% thrust

X1 = 0.07
X2 = 0.30
X3 = 0.85

With ICAO Engine Emissions Databank fuel flows:

Y1 = 0.1090
Y2 = 0.2844
Y3 = 0.8199

→ A = 0.2709
→ B = 0.6622

→C = 0.0613

→ $Y = 0.2709 X^2 + 0.6622 X + 0.0613$ (2)

3) Results for selected thrust (examples)

70% thrust (X = 0.7): equation (2): Y = 0.6576 → multiply with ICAO Engine Emissions Databank maximum rated thrust fuel flow → Fuel flow = 1.388 kg/s

90% thrust (X = 0.9): equation (1): Y = 0.8783 → multiply with ICAO Engine Emissions Databank maximum rated thrust fuel flow → Fuel flow = 1.853 kg/s

A1.6.40 For Option B, performance model would be utilized to obtain/calculate operational fuel flow data using various additional data (e.g. ATOW or stage length or information pertinent to fuel flow calculation) in conjunction with the ICAO EEDB. As examples, models such as BADA or PIANO or ADAECAM may be used

A1.6.41 Emission Indices

A1.6.42 Option A: Emissions indices for Option A will be calculated from the data in the ICAO EEDB using the ‘linear interpolation on a log-log scale’ method as employed in the BFFM2 method, using the fuel flows calculated by the methodology in section A1.6.39.

A1.6.43 Option B: The "operational" emission indices are derived from the data in the ICAO EEDB using the ‘linear interpolation on a log-log scale’ method as employed in the BFFM2 method, using the operational fuel flows from the method described in section A1.6.40

A1.6.44 Application of Additional Parameters that may Influence Emissions, if Appropriate

A1.6.45 Important Caveats For Modelers Using Advanced Methods

A1.6.46 Unlike for the Simple approach, different methods under the heading of Advanced methods may already include some aspects of the corrections for additional parameters such as ambient conditions. It is important to avoid double-accounting in these cases. Hence, the application of the corrections may differ between different methods. It is also important to realize that ambient conditions sufficiently far from standard may cause the airplane or engine to reach operational limits. For instance, many engines will not be able to provide full flat-rated thrust beyond some temperature limit (typically ISA +15C, but this limit varies). The modeler must take care not to extrapolate a methodology beyond the conditions for which it is valid.

A1.6.47 Application to Advanced Approach Option B–

A1.6.48 If an aircraft performance model is used to calculate airplane and engine operating conditions (Advanced Option B), then it should already include the effects of forward speed on the fuel flow. It may, depending on the model, also include the effects of ambient conditions. The modeler must be aware of how the model functions. If it is necessary to correct the airplane performance model and/or fuel flow further to account accurately for these effects, the modeler should do so at this stage.

A1.6.49 After the airplane performance and fuel flow has been correctly determined under Advanced Option B, then the emissions indices should be calculated using a fuel flow method. One documented[6] fuel flow method is the Boeing Fuel Flow Method 2. Depending on the needs of the modeler and the available data other methods may be used, although the BFFM2 is recommended as a default option.

A1.6.50 As described in SAE AIR5715, the BFFM2 accounts for the effects of ambient conditions and forward speed. It is important to recognize that if the effects of ambient conditions and forward speed are to be considered, it is not sufficient to only use the initial calculation of the emission indices from the curve fitting methods defined for the BFFM2. However, the full BFFM2 method includes corrections for both of these effects, so no further corrections to the emissions indices would be required if it is used.

A1.6.51 Application to Advanced Approach Option A

A1.6.52 Methods that fall under Advanced Option A, while less sophisticated and precise, may also be more complicated to adjust for ambient conditions. First the performance of the airplane (thrust, time in mode, etc.) might need to be adjusted to account of ambient conditions. Then, since the fuel flow would have been calculated for the relevant thrust level at ISA static conditions (as the fuel flow is not based on an aircraft performance model in this option), corrections for both ambient conditions and forward speed would need to be implemented. The result would be a fuel flow, corrected for both sets of conditions, but without the accuracy (or temporal and spatial resolution) of an Option B model.

A1.6.53 The calculation of the emission indices and their correction for ambient conditions and forward speed effects could then use the same approach as for Advanced Option B. However, because the fuel flow and flight conditions are not known to the same degree of resolution as with Option B, the results obtained when applying a method such as the BFFM2 might not be accurate or even well-defined. The BFFM2 is only defined at fully specified[7] flight conditions and can not be directly applied to an entire “mode” such as takeoff or climbout. Either a fully specified flight condition could be assumed that represents the airplane for the entire time in mode, or else a different method would have to be used to determine the emissions indices. This different method might be a modification of BFFM2, or it might be unrelated. Thus the application of corrections for forward speed and ambient conditions to an Advanced Option A calculation will depend on the details of the model and the requirements of the modeler.

A1.6.54 Altitude Effects

A1.6.55 The effects of altitude on an aircraft engine are governed by the local pressure, temperature and humidity. Therefore, the effects of altitude on the engine emissions will be correctly treated if the approaches described above are implemented and the ambient conditions used are those local to the airplane in flight.

---

[6] SAE AIR5715

[7] Fully Specified: The state vector (3D position, speed, attitude), engine parameters and airframe configuration are known.

A1.6.56 Engine Deterioration

A1.6.57 While aircraft/engine manufacturers always design their products for peak efficiency at delivery, as aircraft enter revenue service some performance degradation may be experienced over time due to the harsh environments aircraft and engines will operate at. Erosion, seal degradation and dirt build up on finely tuned rotating hardware and airframes over long periods of time can lead to performance loss. If left unchecked, the deterioration can result in noticeable fuel consumption increases over time. Fuel consumption increases are an un-necessary cost increase to the carriers and as a result they will normally perform maintenance on their products to keep the level of performance loss at acceptable levels. An analysis done by CAEP Working Group 3 has assessed the impact of aircraft/engine deterioration and provides the following guidance regarding how and when to apply deterioration in performing airport inventories.

A1.6.58 In-service airframe and engine deterioration for the purposes of airport inventories (i.e., the LTO cycle below 3000 feet) is a small but real effect on fuel burn and NOx emissions. There is no evidence that indicates deterioration effects on CO, HC, or smoke number.

A1.6.59 As a cost savings measure airlines take precautions to keep deterioration effects to a minimum by establishing routine maintenance programs. Based on analyses of theoretical and actual airline data, the magnitude of deterioration effects can be on a fleet-wide basis as follows:

Fuel consumption	+3%
NOx emissions	+3%
CO emissions	no change
HC emissions	no change
Smoke number	no change

A1.6.60 For application to modelling, including emission inventories, the appropriate use of this deterioration information in modelling activities is model/assumption and input data dependent. Specifically, models and assumptions may already include a deterioration allowance, either explicitly (i.e., actual engine operational data or calibrated/validated on actual in-service data), implicitly (i.e., conservative fuel flow correction factors applied to engine certification values), or may already include conservatism which significantly outweighs the fuel consumption and NOx emissions deterioration effects. Care must be taken to avoid double accounting.

A1.6.61 The Simple Approach is a significant over-estimate of aircraft emissions and fuel consumption. The margin of conservatism for the Simple Approach is large enough to preclude the application of deterioration effects.

A1.6.62 The Advanced Approach allows different thrust settings to be applied to fuel flow methodologies as well as some sort of aircraft performance calculations. While the results are more accurate than the Simple Approach, comparison with FDR data suggests that, for commonly used methods, there still is a level of conservatism on a fleet-wide basis on fuel flow calculations resulting from use of performance-estimated times-in-mode, take-off weight and throttle settings in the LTO cycle. The deterioration factors are considered smaller that the inherent conservatism already existing in the method and application is therefore not recommended.

A1.66.3 Where the Sophisticated Approach utilizes actual engine/aircraft operational performance data (including operational fuel flow), then that would inherently include actual deterioration effects. Again the application of deterioration factors is not recommended.

A1.6.64 An exception to the recommendation above might occur in using a combination of advanced and sophisticated methods using actual engine/aircraft combinations, average or measured times-in-mode, TOW and throttle settings, combined with fuel flow rates calculated from ICAO certification data. In this case application of deterioration factors is recommended.

A1.6.65 Fuel consumption deterioration should only be applied to modelling in the vicinity of airports (i.e., the LTO cycle) and should not be used for global modelling where the deterioration factor would be different than the values reported here.

A1.6.66 Start-Up Emissions Calculation Approach

A1.6.67 During the starting sequence there is very little NOx emissions produced compared to the LTO cycle due to the very low engine temperatures and pressures, and the only emissions that requires consideration during the starting sequence is HC. Aircraft main engine starting can generally be broken down into two phases; pre ignition and post ignition.

A1.6.68 Engine Pre-Ignition

A1.6.69 The Pre-ignition phase represents the time when the engine has been cranked using a starter motor and fuel permitted into the combustor to achieve ignition. From starter motor initiation to combustor lighting can take several seconds but there is no fuel entering the engine as the fuel system primes and the fuel valves are closed. Due to the requirement for quick start times, the combustion system is designed so that ignition occurs within the first or second spark of the igniter, typically within 1 second of fuel valves being opened and no later than 2 seconds. This has also been confirmed from rig testing by manufacturers using optical access to see fuel arrive and observed time to ignition.

A1.6.70 Pre ignition emissions would be purely fuel hydrocarbons, as combustion has not been initiated so no fuel is consumed within the combustor. This allows the HC emissions to be calculated directly from the fuel flow. During the pre ignition period three things happen

- The fuel valve is opened
- The fuel injector system fills and fuel flow starts
- The igniter begins to spark and lights the combustor

A1.6.71 Engine Post-Ignition

A1.6.72 At this point the starting process occurs at low engine loading conditions. At these operating points the engine emissions will primarily take the form of HC and CO emissions. Direct measurement of starting emissions is made difficult by unburnt and partially burnt fuel contaminating gas sampling hardware. After ignition at particularly low engine loading, as would be the case during engine starting, emissions of HC dominate. For this reason it is not unreasonable to attribute starting emissions to HC alone resulting in a conservative estimate of HC emissions. CO emissions can be higher than HC for some engines at 7% idle and below, and thus post ignition HC emissions may be significantly lower than the estimate based on combustion efficiency. Detailed emissions measurements would be required to provide a more precise estimate of HC emissions.

A1.6.73 Post ignition emissions are determined from the point of ignition through the acceleration to idle. As the combustor is now burning fuel therefore the rate of consumption must be considered to determine emissions accurately. Gas sampling at sub-idle conditions is very difficult on engines because there are significant amounts of unburned and partially burnt fuel that tends to contaminate the sampling hardware. To get around this issue the analysis is performed using combustion efficiency correlations that have been determined by combustor rig testing at sub-idle conditions. These correlations are based on combustor inlet temperature, combustor inlet pressure, combustor air mass flow, fuel flow and fuel-air ratio. This approach to determining combustion efficiency and heat release is common between all engine manufacturers.

A1.6.74 The instantaneous combustor efficiency is calculated and the resulting inefficiency is allocated as a percentage of unburnt fuel representing the resulting HC emission. Using this process throughout the acceleration to idle the sum of the instantaneous HC emissions can be utilized to provide a conservative estimation of the total post ignition engine HC emission.

A1.6.75 ICCAIA has performed a detailed analysis of engine starting data from GE, RR , P&W and IAE engines and has developed a method to estimate total start up emissions based on the rated sea level thrust of the engine in question. The results of this study were presented to CAEP WG3 in Working Paper CAEP8-WG3-CETG-WP06. In the paper ICCAIA recommends a simple first order linear relationship between HC and the take-off engine thrust rating. The recommended equation is:

STARTING HC EMISSIONS (grams) = Rated Take Off Thrust (kN)/2 + 80	Eq. A1-5

(NOTE: This analysis is based on actual engine testing performed at moderate inlet temperature conditions. The methodology to derive the starting HC emissions was conservative because it did not account for any CO during starting. In addition, applying the methodology to all engines may be optimistic for older engines where fuel distribution controls are not as sophisticated. The methodology also considers typical times to light and typical starting times which in practice could be quite varied and would be longer at very cold conditions. It would be reasonable to state that the uncertainty in the methodology was around +/-50%).

A1.6.76 Advanced Calculation Methodology for NOx, CO and THC

A1.6.77 The calculation of emission masses in the advanced approach makes use of additional data, information and existing models. As such, the emission of an aircraft is a function (f) of the key parameters and the chosen options. This results in having a performance based calculation using various additional data and information that should yield a more accurate emissions inventory that will be unique to the specific airport and study year under consideration.

A1.6..78 To determine the NOx, CO, or HC emissions for a unique aircraft/engine combination, the following formula may be used. This method is repeated for each aircraft/engine type and movement.

$$Ei\ j = \sum (TIM_{jk}*60) * f(FF_{jk}, EI_{jk} \text{ or } Thrust_{jk}, Cond_{j}, Ne_{j}) \qquad \text{Eq. A1-6}$$

where:

Eij = Total emissions of pollutant i (e.g., NOx, CO, or HC), in grams, produced by a specific aircraft j for one LTO cycle

Eijk = The emission index for pollutant i (e.g., NOx, CO, or HC), in grams of pollutant per kilogram of fuel (g/kg of fuel), in mode k for each engine used on aircraft j

FFjk = Fuel flow for mode k, in kilograms per second (kg/s), for each engine used on aircraft type j

Thrustjk = Thrust level for mode k for the aircraft type j

TIMjk = Time-in-mode for mode k, in minutes, for aircraft j

Nej = Number of engines used on aircraft j, considering the potential use of less than all engines during taxi operation.

Condj = ambient conditions (forward speed, altitude, p, t, h) for aircraft type j movement

A1.6.79 Emission Calculation Sophisticated Approach

A1.6.80 Parameters

A1.6.81 Under the Sophisticated Approach, the actual and refined data required for the analysis is obtained from real-time measurements, reported performance information and/or complex computer modeling outputs. At a high level, these data and information characterize the actual fleet composition in terms of aircraft types and engine combinations, TIM, thrust levels, fuel flows and possibly, combustor operating conditions for all phases of ground-based and take-off operations. In some cases, correction of engine operating conditions to reference conditions, using accepted methods will also be required.[8] Additionally, the application of the parameters defined in Sections A1.6.42 – A1.6.65 could be considered based on the guidance provided in Table 1.

A1.6.82 Listed below are the data and information typically required for computing aircraft engine emissions using the Sophisticated Approach.

- Times-in-mode measurements for different aircraft/engine types under different load, route and meteorological conditions.
- Reverse thrust deployment measurements for different aircraft/engine types under different meteorological conditions.
- Airport meteorological conditions, where modelling of aircraft/engine performance accounts for variation in meteorological conditions.
- Frequency and type of engine test runs.
- Frequency of operational aircraft towing.
- Airport infrastructure and constraints (e.g., runway length).

[8] Sources for correcting and obtaining these data will be the airlines, engine manufacturers, ICAO Annex 16 Volume II, SAE AIR 1845, BADA, and ETMS, ETFMS and FDR data.

A1.6.83 Similarly, data measured by operators may be made available, including:

- Typical or actual throttle settings used during reverse thrust operation.
- Actual aircraft/engine configuration data.
- Actual fuel flow data.
- Actual idle engine-type idle speeds.
- Typical or actual throttle settings for approach take off and climb out (e.g. reduced thrust take-off procedures).
- Approach and climb profiles.
- Frequency of less than-all-engine taxi operation.

A1.6.84 This measured and actual operator data may supplement or replace elements of modeled data.

A1.6.85 Using actual performance and operational data, engine emissions factors can be calculated using programs such as the Boeing Fuel Flow Method 2 or the Deutsches Zentrum für Luft- und Raumfahrt Method.

A1.6.86 Sophisticated Calculation Methodology for NOx, CO and THC

A1.6.86 Once the actual fleet engine emissions factors, times-in-mode and fuel flows are known, the LTO emissions are calculated using the same equation used in the Advanced Approach; however with the refined input values.

$$Ei\ j = \sum (TIM_{jk}*60) * f(FF_{jk}, EI_{jk} \text{ or } Thrust_{jk}, Cond_{j}, Ne_{j}) \qquad \text{Eq. A1-7}$$

where:

Eij = Total emissions of pollutant i (e.g., NOx, CO, or HC), in grams, produced by a specific aircraft j for one LTO cycle

Eijk = The emission index for pollutant i (e.g., NOx, CO, or HC), in grams per pollutant per kilogram of fuel (g/kg of fuel), in mode k for each engine used on aircraft j

FFjk = Fuel flow for mode k, in kilograms per second (kg/s), for each engine used on aircraft type j

Thrustjk = Thrust level for mode k for the aircraft type j

TIMjk = Time-in-mode for mode k, in minutes, for aircraft j

Nej = Number of engines used on aircraft j

Condj = ambient conditions (forward speed, altitude, p, t, h) for aircraft type j movement

A1.7 Auxiliary Power Unit Emissions

A1.7.1 An auxiliary power unit (APU) is a small gas-turbine engine coupled to an electrical generator and is used to provide electrical and pneumatic power to aircraft systems when required. It is normally mounted in the tail cone of the aircraft, behind the rear pressure bulkhead, and runs on kerosene fed from the main fuel tanks. Not all aircraft are fitted with APU, and though their use on transport category jet aircraft is now almost universal, some turboprops and business jets do not have an APU fitted.

A1.7.2 Emissions Calculation Methodology

A1.7.3 Unlike aircraft main engines, APU are not certificated for emissions and the manufacturers generally consider information on APU emissions rates as proprietary. As a result, little data are publicly available to serve as a basis for calculating APU emissions. Analysis performed to date on APU's have not been successful in developing Advanced and Sophisticated methodologies that more accurately predict APU emissions if more information is available to the user. As a result, use of the Simple approach, for all cases, is recommended at this time.

A1.7.4 Simple Approach

A1.7.5 If very little information is known about the aircraft types operating at the study airport, then the Simple Approach for APU emissions may be used. However, the results are likely to have a large order of uncertainty associated with their use and emissions. Generalised emissions for APU have been made public. The information is recommended for use as the Simple approach uses averaged proprietary engine-specific values obtained from APU manufacturers

A1.7.6 Where the level of detail of aircraft fleet does not allow for this process to be used, the following values are considered representative of the APU emissions for each aircraft operation at the airport under study (other values may be used if deemed more appropriate):

Aircraft Group	**Short-haul**[9]	**Long-haul**
Duration of APU operation	45 min.	75 min.
Fuel burn	80 kg	300 kg
NOx emissions	700 g	2400 g
HC emissions	30 g	160 g
CO emissions	310 g	210 g
PM10 emissions	25 g	40 g

A1.7.7 The previous fuel burn and emission values are based on averaged manufacturer APU-specific proprietary data; though do not represent any specific APU type. The operational times noted are based on average operating times experienced by a number of operations and do not necessarily represent any specific airport operation. It should be noted that APU operating times vary considerably at different airports due to a number of factors, and can be significantly different to the default values listed in the previous table. If information on actual APU operating times is available, either from surveys or as maximum durations from local airport restrictions, then the APU fuel burn and emissions may be adjusted by factoring these values in the table by the ratio of the survey times with the default values outlined.

A1.7.8 For example, APU NOx emissions for a short-haul aircraft operating for 60 minutes would be calculated as follows:

NOx (g/LTO) = (60 minutes per LTO)) x (700 g/ 45 minutes) = 933 g/LTO

[9] Although there is no common definition of short haul and long haul, in the context of this document we propose a rule of thumb that relates the term to aircraft type. The long haul group would include aircraft capable of a maximum range of more than 8000km, e.g. A330, A4340, A380, B747, B767-200ER, B763, B764, B777, IL96, MD11. Short haul would include all other aircraft.

A1.7.9 In addition, publicly distributed manufacturer information is available showing aircraft and APU combinations including duty cycle average APU EI and fuel burn rates.[10] Air Transport Association (ATA) estimates of APU operating times also are available; based on a limited, informal survey concerning APU usage. Use of the manufacturer APU emissions data, along with the ATA estimates on APU operating times will provide a more accurate estimate of APU emissions. The ATA estimates on APU operating times provide estimates for narrow and wide-body[11] aircraft with and without gate power. As examples, these estimates are provided in the following table (other values may be used if deemed more appropriate):

	ATA Operating Time (hours/cycle)	
Aircraft Type	With Gate Power	Without Gate Power
Narrow Body	0.23 to 0.26	0.87
Wide Body	0.23 to 0.26	1.0 to 1.5

A1.7.10 APU and aircraft combinations can be found in 1995 FAA technical report entitled, Technical Data to Support FAA Advisory Circular on Reducing Emissions from Commercial Aviation [FAA 1995]. This document provides an accurate summary of which major APU family is used on different aircraft. The document also provides modal EI and fuel flow for specific APU; all of which would provide additional detail to the APU emissions calculation.

A1.7.11 For example, APU NOx emissions for a wide body aircraft utilizing a 331-200ER without gate power, where the time at load is 1.5 hours, the NOx EI is 9.51 lb per 1000 lb fuel, and the fuel flow is 267.92 lb per hour.

NOx (lb/LTO) = (1.5 hours per LTO)) x (9.51 lb/1000 lb fuel)*(267.92 lb fuel/hour) = 3.82 lb/LTO = 3,466 g/LTO

[10] Correspondence from Honeywell Engines & Systems to U.S. EPA Assessment and Standards Division, APU Emissions, September 29, 2000.

[11] Narrow Body: single aisle aircraft. Wide body: multiple aisle aircraft e.g. A300, A330, A340, A380, B767, B777, B747.

Chapter 2

Emissions Inventory
Annex 1
Aircraft Emissions
Appendix A
Example ICAO Engine Emissions Datasheet

ICAO ENGINE EXHAUST EMISSIONS DATA BANK

SUBSONIC ENGINES

ENGINE IDENTIFICATION:	Trent 895	BYPASS RATIO:	5.7
UNIQUE ID NUMBER:	5RR040	PRESSURE RATIO (π_{oo}):	41.52
ENGINE TYPE:	TF	RATED OUTPUT (F_{oo}) (kN):	413.05

REGULATORY DATA

CHARACTERISTIC VALUE:	HC	CO	NOx	SMOKE NUMBER
D_p/F_{oo} (g/kN) or SN	1.7	23.1	78.6	6.9
AS % OF ORIGINAL LIMIT	8.6 %	19.6 %	63.9 %	42.8 %
AS % OF CAEP/2 LIMIT (NOx)			79.9 %	
AS % OF CAEP/4 LIMIT (NOx)			87.3 %	

DATA STATUS

- \- PRE-REGULATION
- x CERTIFICATION
- \- REVISED (SEE REMARKS)

TEST ENGINE STATUS

- \- NEWLY MANUFACTURED ENGINES
- x DEDICATED ENGINES TO PRODUCTION STANDARD
- \- OTHER (SEE REMARKS)

EMISSIONS STATUS

- x DATA CORRECTED TO REFERENCE (ANNEX 16 VOLUME II)

CURRENT ENGINE STATUS

(IN PRODUCTION, IN SERVICE UNLESS OTHERWISE NOTED)

- \- OUT OF PRODUCTION
- \- OUT OF SERVICE

MEASURED DATA

MODE	POWER SETTING (%F_{oo})	TIME minutes	FUEL FLOW kg/s	EMISSIONS INDICES (g/kg) HC	CO	NOx	SMOKE NUMBER
TAKE-OFF	100	0.7	4.03	0.02	0.27	47.79	-
CLIMB OUT	85	2.2	3.19	0	0.19	34.29	-
APPROACH	30	4.0	1.05	0	0.54	11.39	-
IDLE	7	26.0	0.33	0.89	14.71	5.11	-
LTO TOTAL FUEL (kg) or EMISSIONS (g)			1357	462	7834	28029	-
NUMBER OF ENGINES				1	1	1	1
NUMBER OF TESTS				3	3	3	3
AVERAGE D_p/F_{oo} (g/kN) or AVERAGE SN (MAX)				1.1	18.8	67.81	5.34
SIGMA (D_p/F_{oo} in g/kN, or SN)				-	-	-	-
RANGE (D_p/F_{oo} in g/kN, or SN)				0.95 - 1.24	17.71 - 19.67	65.76 - 69.5	4.7 - 6.0

ACCESSORY LOADS

POWER EXTRACTION	0	(kW)	AT	-	POWER SETTINGS
STAGE BLEED	0	% CORE FLOW	AT	-	POWER SETTINGS

ATMOSPHERIC CONDITIONS

BAROMETER (kPa)	100.2
TEMPERATURE (K)	287
ABS HUMIDITY (kg/kg)	.0053 - .0089

FUEL

SPEC	AVTUR
H/C	1.95
AROM (%)	16

MANUFACTURER: Rolls-Royce plc
TEST ORGANIZATION: Rolls-Royce plc
TEST LOCATION: SINFIN, Derby
TEST DATES: FROM Sep 94 TO -

REMARKS

1. Data from certification report DNS59304

This document was prepared on 1 October 2004
Check website for latest version

Chapter 2
Emissions Inventory
Annex 1
Aircraft Emissions
Appendix B
Simplified Aircraft Emission Indices

Table B-1 LTO Emission Factor by Aircraft

			LTO emissions factors/airplane (kg/LTO/aircraft)[10]					Fuel consumption (kg/LTO/aircraft)
		Aircraft[11]	**CO_2[9]**	**HC**	**NO_x**	**CO**	**SO_2[8]**	
Source: ICAO (2004)[1]	Large Commercial Aircraft[2]	A300	5450	1.25	25.86	14.80	1.72	1720
		A310	4760	6.30	19.46	28.30	1.51	1510
		A319	2310	0.59	8.73	6.35	0.73	730
		A320	2440	0.57	9.01	6.19	0.77	770
		A321	3020	1.42	16.72	7.55	0.96	960
		A330-200/300	7050	1.28	35.57	16.20	2.23	2230
		A340-200	5890	4.20	28.31	26.19	1.86	1860
		A340-300	6380	3.90	34.81	25.23	2.02	2020
		A340-500/600	10660	0.14	64.45	15.31	3.37	3370
		707	5890	97.45	10.96	92.37	1.86	1860
		717	2140	0.05	6.68	6.78	0.68	680
		727-100	3970	6.94	9.23	24.44	1.26	1260
		727-200	4610	8.14	11.97	27.16	1.46	1460
		737-100/200	2740	4.51	6.74	16.04	0.87	870
		737-300/400/500	2480	0.84	7.19	13.03	0.78	780
		737-600	2280	1.01	7.66	8.65	0.72	720
		737-700	2460	0.86	9.12	8.00	0.78	780
		737-800/900	2780	0.72	12.30	7.07	0.88	880
		747-100	10140	48.43	49.17	114.59	3.21	3210
		747-200	11370	18.24	49.52	79.78	3.60	3600
		747-300	11080	2.73	65.00	17.84	3.51	3510
		747-400	10240	2.25	42.88	26.72	3.24	3240
		757-200	4320	0.22	23.43	8.08	1.37	1370
		757-300	4630	0.11	17.85	11.62	1.46	1460
		767-200	4620	3.32	23.76	14.80	1.46	1460
		767-300	5610	1.19	28.19	14.47	1.77	1780
		767-400	5520	0.98	24.80	12.37	1.75	1750
		777-200/300	8100	0.66	52.81	12.76	2.56	2560
		DC-10	7290	2.37	35.65	20.59	2.31	2310
		DC-8-50/60/70	5360	1.51	15.62	26.31	1.70	1700
		DC-9	2650	4.63	6.16	16.29	0.84	840
		L-1011	7300	73.96	31.64	103.33	2.31	2310
		MD-11	7290	2.37	35.65	20.59	2.31	2310
		MD-80	3180	1.87	11.97	6.46	1.01	1010
		MD-90	2760	0.06	10.76	5.53	0.87	870
		TU-134	5860	35.97	17.35	55.96	1.86	1860
		TU-154-M	7040	17.56	16.00	110.51	2.51	2510
		TU-154-B	9370	158.71	19.11	190.74	2.97	2970

	Regional Jets/Business Jets > 26.7 kN thrust	RJ-RJ85	950	0.67	2.17	5.61	0.30	300
		BAE 146	900	0.70	2.03	5.59	0.29	290
		CRJ-100ER	1060	0.63	2.27	6.70	0.33	330
		ERJ-145	990	0.56	2.69	6.18	0.31	310
		Fokker 100/70/28	2390	1.43	5.75	13.84	0.76	760
		BAC111	2520	1.52	7.40	13.07	0.80	800
		Dornier 328 Jet	870	0.57	2.99	5.35	0.27	280
		Gulfstream IV	2160	1.37	5.63	8.88	0.68	680
		Gulfstream V	1890	0.31	5.58	8.42	0.60	600
		Yak-42M	1920	1.68	7.11	6.81	0.61	610
Source: FAEED222 (3)	Low Thrust Jets (Fn < 26.7 kN)	Cessna 525/560	1060	3.35	0.74	34.07	0.34	340
Source: FOI (4)	Turboprops	Beech King Air (5)	230	0.64	0.30	2.97	0.07	70
		DHC8-100 (6)	640	0.00	1.51	2.24	0.20	200
		ATR72-500 (7)	620	0.29	1.82	2.33	0.20	200

Notes:
(1) ICAO (International Civil Aviation Organization) Engine Exhaust Emissions Data Bank (2004) based on average measured certification data**.**

Emissions factors apply to LTO cycle only. Total emissions and fuel consumption are calculated based on ICAO standard time in mode and thrust levels.

(2) Engine types for each aircraft were selected on a basis of the engine with the most LTOs as of 30 July 2004 (except 747-300 - see text).

This approach, for some engine types, may underestimate (or overestimate) fleet emissions which are not directly related to fuel consumption (eg NOx, CO, HC).

(3) U.S. Federal Aviation Administration (FAA) Emissions and Dispersion Modeling System (EDMS) non-certified data

(4) FOI (The Swedish Defense Research Agency) Turboprop LTO Emissions database non-certified data

(5) Representative of Turboprop aircraft with shaft horsepower of up to 1000 shp/engine

(6) Representative of Turboprop aircraft with shaft horsepower of 1000 to 2000 shp/engine

(7) Representative of Turboprop aircraft with shaft horsepower of more than 2000 shp/engine

(8) The sulphur content of the fuel is assumed to be 0.05% [Same assumption as in 1996 IPCC NGGIP revision]

(9) CO2 for each aircraft based on 3.16 kg CO2 produced for each kg fuel used, then rounded to the nearest 10 kg.

(10) Information regarding the uncertainties associated with the data can be found in the following references:

QinetiQ/FST/CR030440 "EC-NEPAir: Work Package 1 Aircraft engine emissions certification – a review of the development of ICAO Annex 16, Volume II", by D H Lister and P D Norman

ICAO Annex 16 "International Standards and Recommended Practices Environmental Protection", Volume II "Aircraft Engine Emissions", 2nd edition (1993)

(11) Equivalent aircraft are contained in Table B-3

Table B-2 Engine Designations by Aircraft

Aircraft	ICAO Engine	Engine UID
A300	PW4158	1PW048
A310	CF6-80C2A2	1GE016
A319	CFM56-5A5	4CM036
A320	CFM56-5A1	1CM008
A321	CFM56-5B3/P	3CM025
A330-200/300	Trent 772B-60	3RR030
A340-200	CFM56-5C2	1CM010
A340-300	CFM56-5C4	2CM015
A340-500/600	TRENT 556-61	6RR041
707	JT3D-3B	1PW001
717	BR700-715A1-30	4BR005
727-100	JT8D-7B	1PW004
727-200	JT8D-15	1PW009
737-100/200	JT8D-9A	1PW006
737-300/400/500	CFM56-3B-1	1CM004
737-600	CFM56-7B20	3CM030
737-700	CFM56-7B22	3CM031
737-800/900	CFM56-7B26	3CM033
747-100	JT9D-7A	1PW021
747-200	JT9D-7Q	1PW025
747-300	JT9D-7R4G2(66%) RB211-524D4(34%)	1PW029(66%) 1RR008(34%)
747-400	CF6-80C2B1F	2GE041
757-200	RB211-535E4	3RR028
757-300	RB211-535E4B	5RR039
767-200	CF6-80A2	1GE012
767-300	PW4060	1PW043
767-400	CF6-80C2B8F	3GE058
777-200/300	Trent 892	2RR027
DC-10	CF6-50C2	3GE074
DC-8-50/60/70	CFM56-2C1	1CM003
DC-9	JT8D-7B	1PW004
L-1011	RB211-22B	1RR003
MD-11	CF6-80C2D1F	3GE074
MD-80	JT8D-217C	1PW018
MD-90	V2525-D5	1IA002
TU-134	D-30-3	1AA001
TU-154-M	D-30-KU-154-II	1AA004
TU-154-B	NK-8-2U	1KK001
RJ-RJ85	LF507-1F, -1H	1TL004
BAE 146	ALF 502R-5	1TL003
CRJ-100ER	CF34-3A1	1GE035
ERJ-145	AE3007A1	6AL007
Fokker 100/70/28	TAY Mk650-15	1RR021
BAC111	Spey-512-14DW	1RR016
Dornier 328 Jet	PW306B	7PW078
Gulfstream IV	Tay MK611-8	1RR019

Gulfstream V	BR700-710A1-10	4BR008
Yak-42M	D-36	1ZM001
Cessna 525/560	PW545A or similar	FAEED222
Beech King Air	PT6A-42	PT6A-42
DHC8-100	PW120 or similar	PW120
ATR72-500	PW127F or similar	PW127F

Table B-3 Representative Aircraft

Generic Aircraft	ICAO	IATA aircraft in group
	A30B	AB3
		AB4
		AB6
		ABF
		ABX
Airbus A300	A306	ABY
		310
		312
		313
		31F
		31X
Airbus A310	A310	31Y
	A319	319
Airbus A319	A318	318
		320
Airbus A320	A320	32S
Airbus A321	A321	321
	A330	330
Airbus A330-200	A332	332
	A330	330
Airbus A330-300	A333	333
Airbus A340-200	A342	342
	A340	340
Airbus A340-300	A343	343
Airbus A340-500	A345	345
Airbus A340-600	A346	346
		703
		707
		70F
Boeing 707	B703	70M
Boeing 717	B712	717
		721
Boeing 727-100	B721	72M
		722
Boeing 727-200	B722	727

		72C
		72B
		72F
		72S
Boeing 737-100	B731	731
		732
		73M
Boeing 737-200	B732	73X
		737
		73F
		733
Boeing 737-300	B733	73Y
		737
Boeing 737-400	B734	734
		737
Boeing 737-500	B735	735
Boeing 737-600	B736	736
		73G
Boeing 737-700	B737	73W
		738
Boeing 737-800	B738	73H
Boeing 737-900	B739	739
	B741	74T
	N74S	74L
	B74R	74R
Boeing 747-100	B74R	74V
		742
		74C
Boeing 747-200	B742	74X
		743
Boeing 747-300	B743	74D
		747
		744
		74E
		74F
		74J
		74M
Boeing 747-400	B744	74Y
		757
		75F
Boeing 757-200	B752	75M

Boeing 757-300	B753	
Boeing 767-200	B762	762
		76X
Boeing 767-300	B763	767
		76F
		763
		76Y
Boeing 767-400	B764	
Boeing 777-200	B772	777
		772
Boeing 777-300	B773	
		773
Douglas DC-10	DC10	D10
		D11
		D1C
		D1F
Douglas DC-10	DC10	D1M
		D1X
		D1Y
Douglas DC-8	DC85	D8F
	DC86	D8L
	DC87	D8M
		D8Q
		D8T
		D8X
		D8Y
Douglas DC-9	DC9	DC9
	DC91	D91
	DC92	D92
	DC93	D93
	DC94	D94
	DC95	D95
		D9C
		D9F
		D9X
Lockheed L-1011	L101	L10
		L11
		L15
		L1F
McDonnell Douglas MD11	MD11	M11
		M1F

		M1M
McDonnell Douglas MD80	MD80	M80
	MD81	M81
	MD82	M82
	MD83	M83
	MD87	M87
	MD88	MD88
McDonnell Douglas MD90	MD90	M90
Tupolev Tu134	T134	TU3
Tupolev Tu154	T154	TU5
Avro RJ85	RJ85	AR8
		ARJ
BAe 146	B461	141
	B462	142
	B463	143
		146
		14F
		14X
		14Y
		14Z
Embraer ERJ145	E145	ER4
		ERJ
Fokker 100/70/28	F100	100
	F70	F70
	F28	F21
		F22
		F23
		F24
		F28
BAC 111	BA11	B11
		B12
		B13
		B14
		B15
Dornier Do 328	D328	D38
Gulfstream IV / V		GRJ
Yakovlev Yak 42	YK42	YK2

Chapter 2
Emissions Inventory
Annex 1
Aircraft Emissions
Appendix C
Definition of Publicly Available Databases for Use in the Matching Aircraft Type with Engine Type

Useful data fields in the IOAG Database:

LveTime	=	time flight is scheduled to depart origin in local time
LveGMT	=	time flight is scheduled to depart origin in Greenwich Mean Time (GMT)
ArrCode	=	number representing arrival airport
Arrive	=	arrival airport alphabetic code (e.g., JFK)
ArrTime	=	time flight is scheduled to arrive in local time
ArrGMT	=	time flight is scheduled to arrive in GMT
Equip	=	type of aircraft, in code (e.g., B738)
FAACarr	=	abbreviation for air carrier name
FltNo	=	flight number
Freq	=	1/0 code showing days of the week that that flight flies that time slot and city pair
ATACarr	=	carrier name in Air Transport Association Code
IOAGCARR	=	air carrier company in 2-letter IOAG code
CarrType	=	commuter or carrier company
ATAEquip	=	aircraft type in ATA code
EqType	=	J for Jet, T for Turboprop, P for propeller-driven aircraft
CarrName	=	air carrier company name spelled out
LveCity	=	origin city and country/state, spelled out
ArrCntry	=	destination country or state if the destination is in the US
LveCntry	=	origin country or state if the origin is in the US
YYMM	=	year and month of the current schedule
Eday	=	0/1 code indicating whether this flight flies on each day of the month given by the schedule
FPM	=	number of times (days) this fight is flown between this city-pair at this time slot in a month

Useful data fields in the BACK World Fleet Registration Database:

- Aircraft Type
- Aircraft Serial Number
- Aircraft Manufacturer
- Registration\Tail Number
- Engine Manufacturer
- Engine Model
- Number f Engines
- Aircraft Noise Class (Stage)
- Equipment Category
- Equipment Type (LAR Code)
- Equipment Type (IOAG Code)
- Aircraft Equipment Model
- Operator Category
- Operator Name
- Operator IATA Code
- Operator ICAO Code
- Wing Span (meters)
- Wing Area (square meters)
- Overall Length (meters)

- Belly Volume (cubic meters)
- Fuel Capacity
- Maximum Takeoff Weight (kilograms)
- Maximum Payload (kilograms)
- Maximum Landing Weight (kilograms)
- Range with Maximum Fuel (kilometres)
- Range with Maximum Payload (kilometres)

Useful data fields in the ASQP Database:

- IATA carrier code
- Flight number
- Depart airport
- Arrival airport
- Date of operation
- Day of week
- IOAG depart time
- Actual depart time
- IOAG arrival time
- CRS arrival time
- Actual arrival time
- Wheels off time
- Wheels on time
- Aircraft Tail number
- Taxi out time
- Taxi in time

Useful data fields in the JP Airline Fleets Database:

- Operator Name
- Operator IATA Code
- Operator ICAO Code
- Aircraft Tail number
- Aircraft type and subtype
- Month and year of manufacturing
- Construction number
- Previous identity
- Number of engines
- manufacturer of engines
- exact type of engines
- Maximum Takeoff Weight (kilograms)
- Seat configuration (or other use than for passenger services)

APPENDIX
LIST OF REFERENCES

FAA, 1995, Technical Data to Support FAA Advisory Circular on Reducing Emissions from Commercial Aviation, http://www.epa.gov/otaq/regs/nonroad/aviation/meta-faa.txt .

IPCC, 1999, Aviation and the Global Atmosphere, Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0 521 66404 7.

B. Kärcher et al., Particles and cirrus clouds (PAZI) - Overview of results 2000-2003. In: Proceed. European Workshop Aviation, Aerosols and Climate, R. Sausen and G.T. Amanatidis (Eds.), *Air Pollution Research Report No. 83*, Commission of the European Communities, 197-206, 2004.

Hagen, D.E., P.D. Whitefield and H. Schlager (1996) Particle emissions in the exhaust plume from commercial jet aircraft under cruise conditions, *J. Geophys. Res.*, *101*, 19,551-19,557.

B. Kärcher et al., Particles and cirrus clouds (PAZI) - Overview of results 2000-2003. In: Proceed. European Workshop Aviation, Aerosols and Climate, R. Sausen and G.T. Amanatidis (Eds.), *Air Pollution Research Report No. 83*, Commission of the European Communities, 197-206, 2004.

Coordinating Research Council, Inc., Handbook of Aviation Fuel Properties, Third Edition CRC Report No. 635, Alpharetta, GA, USA, 2004.

Hagen, D.E., P.D. Whitefield and H. Schlager (1996) Particle emissions in the exhaust plume from commercial jet aircraft under cruise conditions, *J. Geophys. Res.*, *101*, 19,551-19,557.

NRC, 1988, Research Priorities for Airborne Particulate Matter: I. Immediate Priorities and a Long-Range Research Portfolio, Committee on Research Priorities for Airborne Particulate Matter, National Research Council, http://www.nap.edu/catalog/6131.html.

NRC, 2004, Research Priorities for Airborne Particulate Matter: IV. Continuing Research Progress, Committee on Research Priorities for Airborne Particulate Matter, National Research Council, http://www.nap.edu/catalog/10957.html.

EPA, 2004, Particulate Matter Research Program, five years of progress, http://www.epa.gov/pmresearch/pm_research_accomplishments/pdf/pm_research_program_five_years_of_progress.pdf

NARSTO, 2004, NARSTO (2004) Particulate Matter Assessment for Policy Makers: A NARSTO Assessment. P. McMurry, M. Shepherd, and J. Vickery, eds. Cambridge University Press, Cambridge, England. ISBN 0 52 184287 5.

Petzold, A. and F.P. Schröder (1998) Jet engine exhaust aerosol characterization, *Aerosol Sci. Technol.*, *28*, 62-76.

Petzold, A., R. Busen, F.P. Schröder, R. Baumann, M. Kuhn, J. Ström, D.E. Hagen, P.D. Whitefield, D. Baumgardner, F. Arnold, S. Borrmann, and U. Schumann (1997) Near field measurements on contrail properties from fuels with different sulfur content, *J. Geophys. Res.*, *102*, 29,867-29,880.

Petzold, A., A. Döpelheuer, C.A. Brock, and F.P. Schröder (1999) In situ observations and model calculations of black carbon emission by aircraft at cruise altitude, *J. Geophys. Res.*, *104*, 22171-22181.

Petzold, A. and F.P. Schröder (1998) Jet engine exhaust aerosol characterization, *Aerosol Sci. Technol.*, *28*, 62-76.

Petzold, A., R. Busen, F.P. Schröder, R. Baumann, M. Kuhn, J. Ström, D.E. Hagen, P.D. Whitefield, D. Baumgardner, F. Arnold, S. Borrmann, and U. Schumann (1997) Near field measurements on contrail properties from fuels with different sulfur content, *J. Geophys. Res.*, *102*, 29,867-29,880.

Petzold, A., A. Döpelheuer, C.A. Brock, and F.P. Schröder (1999) In situ observations and model calculations of black carbon emission by aircraft at cruise altitude, *J. Geophys. Res.*, *104*, 22171-22181.

Petzold A et al, Particle emissions from aircraft engines – a survey of the European project PartEmis, Meterologische Zeitschrift, Vol. 14, No. 4, 465-476 (August 2005).

SAE AIR5715, Procedure for the Calculation of Aircraft Emissions, http://www.sae.org/technical/standards/AIR5715 , (July 2009).

Schumann U., J. Ström, R. Busen, R. Baumann, K. Gierens, M. Krautstrunk, F.P. Schröder and J. Stingl (1996) In situ observations of particles in jet aircraft exhausts and contrails for different sulfur-containing fuels, *J. Geophys. Res.*, *101*, 6853-6869.

Schumann, U., F. Arnold, R. Busen, J. Curtius, B. Kärcher, A. Kiendler, A. Petzold, H. Schlager, F. Schröder, and K.H. Wohlfrom (2002) Influence of fuels sulfur on the composition of aircraft exhaust plumes: The experiments SULFUR 1-7, *J. Geophys. Res.*, *107* (10.1029/2001JD000813), AAC 2-1 – AAC 2-27.

Whitefield, P.D., D. Hagen, J. Wormhoudt, R.C. Miake-Lye, C. Wilson, K. Brundish, I.A. Waitz, S. Lukachko, and C.K. Yam, 2002: NASA/QinetiQ Collaborative Program – Final Report, NASA TM-2002-211900 and ARL-CR-0508, NASA, Washington, DC, USA, 193 pp.

EXAMPLES OF MODELLING SYSTEMS

The following list contains examples of modelling systems for airport local air quality studies. This list is neither complete nor prescriptive.

Name and Version	**Availability**	**Website**
ADMS	Application, publicly available	www.cerc.co.uk
ALAQS-AV	Experimental, available to Eurocontrol member states and other users by special agreement.	www.eurocontrol.int
AEDT-EDMS 5.1	Application, publicly available	www.faa.gov
LASPORT 2.0	Application, publicly available	www.janicke.de

Chapter 2
Emissions Inventory
Annex 1
Aircraft Emissions
Appendix D

First Order Approximation v3.0 Method for Estimating PM Emissions from Aircraft Engines

FIRST ORDER APPROXIMATION V3.0 (FOA3.0) for ESTIMATING PARTICULATE MATTER (PM) EMISSIONS from AIRCRAFT ENGINES

Nomenclature

AFR	Air-to-Fuel Ratio (mass basis).
BPR	By-Pass Ratio.
CI	Carbon Index. A measure of the black carbon mass per standard volume of flow. The volume is in standard cubic meters Standard atmosphere is defined as the volume occupied at 273.15 degrees Kelvin and 1 atmosphere of absolute pressure). (mg/m3 produced by burning 1 kg fuel).
EI	Emission Index. A pollutant emission rate based on one kilogram of fuel burned. The units of an EI are normally given as g/kg fuel. However, for convenience the units of mg/kg of fuel are used in this document unless explicitly stated otherwise.
EI_{HC}	Emission index for total hydrocarbons as listed in the ICAO Data Bank. (g/kg fuel)
$EI_{HCCFM56}$	Emission index for total hydrocarbons for the CFM56-2-C5 engine as listed in the ICAO Data Bank (g/kg fuel).
$EI_{PMvol\text{-}orgCFM56}$	Emission index for CFM56-2-C1 engine as derived in the APEX1 measurements. (mg/kg fuel)
$EI_{HCEngine}$	Emission index for total hydrocarbons from the ICAO Data Bank for the subject engine. (g/kg fuel)
$EI_{PMnvols}$	Emission Index for non-volatile particulate matter primarily consisting of black carbon. (mg/kg fuel)
$EI_{PMtotal}$	Total particulate matter emission index for both volatile and non-volatile components. (mg/kg fuel)
$EI_{PMvol-FSC}$	Emission Index for volatile sulphate particulate matter due to fuel sulphur. (mg/kg fuel)
$EI_{PMvol\text{-}FuelOrganics}$	Emission index for organic volatile particulate matter primarily due to incomplete combustion of fuel. (mg/kg fuel)
HC	Total hydrocarbons.
ICAO	International Civil Aviation Organization.
FOA	First Order Approximation. FOA3.0 is the latest version of the methodology to provide emission indexes for particulate matter emitted from aircraft listed in the ICAO Data Bank.
FSC	Fuel sulphur content. (mass fraction)
LTO	ICAO Landing Take-Off cycle.
MW_{out}	Molecular weight of SO_4^{-2} (S^{VI} = 96).
$MW_{Sulphur}$	Molecular weight of elemental sulfur (S^{IV} = 32).
PM	Particulate Matter.
Q_{core}	Exhaust volumetric flow rate as related to fuel burn (m^3/kg fuel).
Q_{Mixed}	Exhaust volumetric flow rate including that due to fuel burn and the bypass air (m^3/kg fuel).
SF	Scaling factor.

SN	Smoke Number. The methodology in this document based on smoke numbers as defined in Appendix 2 in the ICAO Annex 16 document.
SN_{mode}	Smoke number for one of the ICAO defined modes (take-off, climb-out, approach, or idle).
SN_{max}	Maximum smoke number.
STP	Standard temperature and pressure. As used in this document is 273.15 degrees Kelvin and 1 atmosphere of absolute pressure.
ε	Fuel sulphur conversion efficiency (mass fraction).
δ	Ratio of $\frac{EI_{PM\,vol-orgCFM56}}{EI_{HC\,CFM56}}$ as derived for use in Equation 9 (mg/kg).

1. Introduction

FOA3.0 is a method for estimating the particulate emissions both non-volatile (soot) and volatile in the form of Emission Indices (EIs) as mass emitted per kilogram of fuel.[1,2] Currently there are three components to the estimation process and each must be calculated separately, with the total EI being the sum of the parts. The basic technique for each component of Particulate Matter (PM) is as follows.

1.1 Non-volatile PM ($EI_{PMnvols}$)

The calculation of non-volatile PM is based on the engine's Smoke Number (SN), Air Fuel Ratio (AFR) and if applicable its by-pass ratio (BPR). The essence of the technique is to convert the SN via an experimental correlation into a Carbon Index (CI). The CI is the mass of non-volatile PM per unit volume of exhaust. Using the engine AFR and BPR the volume of the exhaust (Q) per kilogram of fuel is calculated thence the product CI and Q gives the EI with the unit of mass per kilogram of fuel burn. Units as reported in this work are mg/kg of fuel unless otherwise stated. The EI must be computed for the various power settings used in the vicinity of airports for $EI_{PMnvols}$.

1.2 Volatile Sulphate PM ($EI_{PMvol-FSC}$)

Volatile sulphate PM is formed from the fuel sulphur via oxidation of SO_2 (S^{IV}) to SO_3 (S^{VI}) and subsequent hydration, in the exhaust plume, of the SO_3 to H_2SO_4. The EI is calculated from the fuel sulphur content and the conversion rate of S^{IV} to S^{VI} (ε). As such, the EI is does not vary by power setting.

1.3 Volatile Organic PM ($EI_{PMvol-FuelOrganics}$)

Measurements of condensable organics in the engine exhaust are very limited. Based on the assumption that condensable organics are directly related to unburned hydrocarbons, an estimate is made by scaling the engine's reported ICAO (International Civil Aviation Administration) Hydrocarbon (HC) EI to those of other engines in the database. Making a second assumption that modern engines behave in a similar manner, the HC ratio can be multiplied by the volatile organic PM EI for the CFM56-2-C1 engine which was measured during NASA's Aircraft Particle Emissions Experiment 1 (APEX1).[3] The result is an EI that is both engine and power setting specific for the volatile organic PM.

1.4 PM from Engine Lubricant

Data are not available to allow prediction of this EI for PM. It is currently assumed, based upon measurement results from APEX1, that the present EI volatile organic PM includes a contribution due to lubrication oil.

2. Data Sources

2.1 ICAO Engine Emissions Data Bank

Values of SN, EI_{HC} and BPR for engines can be found in the ICAO Data Bank for the four power settings of the Landing Take-off cycle (LTO). Unfortunately there are gaps in the data bank for SN and BPR values. This problem is being addressed by ICAO's Committee on Aviation Environmental Protection as follows:

- Addition of new engine data by late 2008.
- Clarification for mixed turbofans as to whether the measurements were made on the engine core or over both the core and by-pass flows by late 2008.
- Addition of missing SN data by late 2008.

Since the SN data within the ICAO emissions data bank is fragmentary for many engines, some only showing the maximum SN, general guidelines have been developed to help fill-in the data gaps. These guidelines apply when instead of a listed value the symbol "-" or "NA" appears which denotes that either the SN was not derived at that particular power setting or it was not reported since only the maximum is required. These guidelines were developed by Calvert[4] and are based on analyzing modal trends within groups of engines to derive scaling factors that can be used to predict the missing data. A scaling factor is a ratio of a modal SN to the maximum SN for an engine:

$$SF = \frac{SN_{mode}}{SN_{max}} \qquad (1)$$

where SF = Scaling Factor
SN_{mode} = SN for one of the modes (take-off, climb-out, approach, or idle)
SN_{max} = Maximum SN

In order to reduce the uncertainties in developing the SF values, SNs with values less than 6 were excluded from the analysis. The resulting SF values are presented in Table 1. The majority of engines are covered by the category non DAC (Double Annular Combustor) engines, however, Aviadgatel, General Electric CF34, Textron Lycoming and DAC engines have significantly different SF vales from the norm.

Engine Category	Takeoff	Climb-out	Approach	Idle
Most non-DAC engines	1.0	0.9	0.3	0.3
Aviadgatel engines	1.0	1.0	0.8	0.3
GE CF34 engines	1.0	0.4	0.3	0.3
Textron Lycoming engines	1.0	1.0	0.6	0.3
GE and CFM DAC engines	0.3	0.3	0.3	1.0

Table 1. Suggested SF Values to Predict Missing SNs within the ICAO Emissions Databank.

Using these SF values and Equation 1, missing SN data can be reasonably filled-in if at least one of the modal SN values for an engine is known.

It is also important to note that in addition to the missing SNs in the ICAO Data Bank, other concerns also exist. If a SN is listed as zero (0) by the manufacturers no attempt has been made to change the value. In these cases, non-volatile PM estimates will be also be zero which is unrealistic but it was considered to be undesirable by the group to change any listed values. In some cases the SN for the idle power setting is listed with an asterisk (*) as a superscript. This indicates that the SN has been calculated at a power setting other than 7%. Finally, if the value is preceded by the symbol “<” the provided value should still be used.

To assist in on-going analysis, a separate table has been included in spreadsheet form (Calvert-method-Databank-Issue_15-C.xls) as the interim recommended values. Manufacturers are working to include all SNs for engines still in production in the ICAO Data Bank and those values will replace those included in the table.

2.2 Air-Fuel-Ratio (AFR)

AFR is not included in the ICAO Data Bank. This problem has been overcome by the use of average fleet AFRs. These generic values were agreed with representatives of the three main engine manufacturers and are shown in Table 2.

Power Setting	AFR
7% (idle)	106
30% (approach)	83
85% (climb-out)	51
100% (take-off)	45

Table 2. Representative Air-Fuel-Ratios Listed by ICAO Power Settings (Mode)

2.3 Non-Volatile PM ($EI_{PMnvols}$)

The calculation of $EI_{PMnvols}$ is accomplished by first computing the CI, which is based on a statistical correlation with the ICAO SN being the independent variable. Derivation of the appropriate SN when the value is not available in the ICAO Data Bank was described in Section 2.1. Also of note is that the statistical correlation equation that must be used has two forms depending on the value of the SN. The dividing line is a SN value of less than or equal to 30 or above 30.

The independent variable for the derivation of the flow rate is the AFR which was listed for each power setting (mode) in Section 2.2. Of note is that two possible choices exist for the appropriate flow rate to use. This is due to SNs being listed either by core flow or mixed flow in the ICAO Data Bank. The listing in the ICAO Data Bank for Engine Type (TF or MTF) allows the choice to be easily made. However, the Data Bank is undergoing changes and the user should be careful in their choice.

The CI must then be multiplied by the appropriate flow rate to determine $EI_{PMnvols}$.

2.4 Volatile Sulphate PM ($EI_{PMvol-FSC}$)

Fuel sulphur contents (FSC) can vary widely between different batches of aviation fuel and are not included in the ICAO Data Bank. For application to the FOA airport, this input has been left as a variable to allow the most applicable value, such as the national and/or international mean sulphur contents, should be used. As a guide, typical FSC values rang from 0.005 to 0.068 weight percent[5] with a global average of 0.03 weight percent[6]. Using a conservative value of 0.068 weight percent is currently recommended in the absence of more specific FSC data.

There is uncertainty about the S^{IV} to S^{VI} conversion process, the non-linear production of S^{VI} that varies with changing FSC and engine operating conditions. The variable for fuel sulphur conversion efficiency (ε) may be input directly by the practitioner if detailed information is known. However, the value is often unknown and a default value is recommended in these situations. Based on the most recent measurements from APEX and PARTEMIS[7], the range of the sulphur conversion efficiency can range from 0.5 to over 3.5 wt%. A median value of 2.4 wt%, based on the APEX measurements, is recommended as the default value. The value of the fuel sulphur conversion efficiency is still a topic of ongoing research and future refinements are expected.

2.5 Volatile Organic Aerosol ($EI_{vol-FuelOrganics}$)

Organic Volatile PM is calculated from the engine ratio of EI_{HC} reported in the ICAO databank with the denominator being the EI_{HC} for the CFM56-2-C5 engine which is the closest value to the engine measured during APEX1[3]. This ratio is multiplied by the measured volatile organic PM EI from APEX1 for the CFM56-2-C1 engine. The measured values are shown in Table 3.

LTO Mode	$EI_{PMVol\text{-}orgCFM56}$ (mg/kg fuel)
Take-off	4.6
Climb-out	3.8
Approach	4.5
Idle	11.3

Table 3. Measured Volatile EI from Reference 1 Used to Calculate Organic Volatile PM.

3. PM EI Calculation

3.1 Non-volatile PM ($EI_{PMnvols}$)

The CI at STP for SN ≤ 30 is calculated from Equation 2[8].

$$CI = 0.0694\,(SN)^{1.234}\ mg/m^3 \text{ based on } 1\,kg \text{ of fuel burn} \quad (2)$$

For SN > 30 Equation 3 should be used.

$$CI = 0.0297\,(SN)^2 - 1.802\,(SN) + 31.94\ \ mg/m^3 \text{ based on } 1\,kg \text{ of fuel burn} \quad (3)$$

The exhaust volumetric flow rate at STP for the engine core is:

$$Q_{Core} = 0.776\,(AFR) + 0.877\ \ m^3/kg \quad (4)$$

Where AFR is the mode specific value from Table 2.

It should be noted that the constants in this equation have the units of m^3/kg of fuel. Similarly, constants used for other equations listed in this document will have units.

And for a mixed (core and by-pass) flow:

$$Q_{Mixed} = 0.776\,(AFR)(1+BPR) + 0.877\ \ m^3/kg \quad (5)$$

$$EI_{PM\,nvol} = (CI)(Q)\ \ mg/kg\ fuel \quad (6)$$

3.2 Volatile Sulphate PM ($EI_{PMvol-FSC}$)

The EI for sulphate PM is calculated from:

$$EI_{PMvols-FSC} = (10^6)\left[\frac{(FSC)(\varepsilon)(MW_{out})}{MW_{Sulphur}}\right]\ mg/kg \quad (7)$$

Where MW_{out} = 96 (SO_4^{-2}) and $MW_{Sulphur}$ = 32. The values of FSC and ε are user defined with default values as previously defined.

3.3 Volatile Organic PM ($EI_{PMvol - Fuel\ Organics}$)

The EI of the volatile organic PM is calculated from:

$$EI_{PMvol\text{-}Fuel\,Organics} = \frac{EI_{PM\,vol-orgCFM56}}{EI_{HCCFM56}} (EI_{HC\,Engine})\ \ mg/kg \qquad (8)$$

Where $EI_{HCCFM56}$ is the ICAO total hydrocarbon emission index for the CFM56-2-C1 engine. $EI_{PMvol-orgCFM56}$ is the APEX1 measured volatile organics EI from Table 3, and. $EI_{HCEngine}$ is the EI_{HC} from the ICAO Data Bank for the subject engine (engine where the EI is being determined). Of note is: 1) the units of $EI_{HCEngine}$ and $EI_{HCCFM56}$ are g/kg fuel as listed in the ICAO Data Bank and cancel; and, 2) that the ratio of $EI_{PMvol-orgCFM56}$ and $EI_{HCCFM56}$ is a constant for each mode. Since only the modal value of the EI_{HC} for the subject engine changes, a simplification can be made to Equation 8 which is easier to calculate. This results in:

$$EI_{PMvol\text{-}Fuel\,Organics} = (\delta)(EI_{HC\,Engine})\ mg/kg \qquad (9)$$

Where δ is constant ratio by mode. Values of this constant are given in Table 4 for each mode.

LTO Mode	**δ (mg/g)**
Take-off	115
Climb-out	76
Approach	56.25
Idle	6.17

Table 4. Modal Values for the Ratio of $EI_{PMVol-orgCFM56}$ and $EI_{HCCFM56}$ in Equation 8

4. Example Calculations

This example is based on calculating PM EIs for the JT8D-217 series engines with an ICAO UID of 1PW018. Derived values are presented for all modes while complete calculations are only shown for the idle since the process is simply repeated for the other modes using appropriate variables. Of course the PM for sulphur does not change by power setting and is the same for all modes. HC EI and SN data for the idle mode from the ICAO Emission Data Bank for this engine is shown in Table 5.

LTO Mode	EI_{HC} (g/kg)	SN
Takeoff	0.28	13.2
Climb	0.43	Missing
Approach	1.6	Missing
Idle	3.33	Missing
Maximum Value	NA	13.3

Table 5. ICAO Data for the JT8D-217 Series Engine, Idle Mode.

To fill-in the missing SN value for the idle mode, a scaling factor of 0.3 from Table 1 corresponding to "most non-DAC engines" and the idle mode is used:

$$SN_{mode} = (0.3)(13.3) = 3.99$$

To calculate non-volatile PM EI ($EI_{PMnvols}$) as function of SN, since the SN< 30, Equation 2 is used.

$$CI = 0.0694(3.99)^{1.234} = 0.383\ mg/m^3$$

Based on the ICAO Data Bank, the mixed exhaust volumetric flow rate should be used with a bypass ratio of 1.73. Using the idle AFR of 106 (Table 2), the exhaust volumetric flow rate is calculated, via Equation 5, as follows:

$$Q_{Mixed} = 0.776(106)(1+1.73)+0.877 = 225.436\ m^3/kg\ fuel$$

Hence:

$$EI_{PMnvols} = (0.383)(225.436) = 86.3\ mg/kg \text{ or } 0.086\ g/kg$$

Assuming a fuel sulfur content of 0.068 wt% (fraction 0.00068) and a S^{IV} to S^{VI} conversion rate of 2.4 wt% (fraction 0.024), the modal independent $EI_{PMvol\text{-}FSC}$ is calculated as follows:

$$EI_{PMvol\text{-}FSC} = (10^6)\left[\frac{(0.00068)(0.024)(96)}{32}\right] = 49.0\ mg/kg \text{ or } 0.049\ g/kg$$

The $EI_{PMvol - Fuel\ Organics}$ may be calculated using the values in Table3, Table 5, and the EI_{HC} for the specific engine as listed in the ICAO Data Bank corresponding to the idle mode:

$$EI_{PMvol\text{-}FuelOrganics} = \frac{11.3}{1.83}(3.33) = 20.6\ mg/kg \text{ or } 0.021\ g/kg$$

Alternatively, the values in Table 5 may be multiplied by the EI_{HC} for the specific engine as listed in the ICAO Data Bank as:

$$EI_{PMvol\text{-}FuelOrganics} = (6.17)(3.33) = 20.5\ mg/kg$$

In summary, the example calculation results of applying FOA3 to the idle mode for the JT8D-217 series engine are:

$$EI_{PMnvols} = 86.3\ mg / kg$$

$$\mathrm{EI}_{\mathrm{PMvol-FSC}} = 49.0\ mg / kg$$

$$\mathrm{EI}_{\mathrm{PMvol-FuelOrganics}} = 20.6\ mg / kg$$

The total EI for all components of PM emissions is then:

$\mathrm{EI}_{\mathrm{PMtotal}}$ = 86.3 + 49.0 + 20.6 = 155.9 *mg / kg* of fuel or 0.156 *g/kg* of fuel burn.

While the EI for sulphur does not change by power setting, the other EIs must be calculated for each mode. Table 6 shows the results for all modes. Of note is that the maximum smoke number was used for the non-volatile PM EI estimates.

ICAO Defined Power Setting (mode)	$\mathrm{EI}_{\mathrm{PMn\text{-}vols}}$	$\mathrm{EI}_{\mathrm{PMvols\ -\ FSC}}$	$\mathrm{EI}_{\mathrm{PMvol\text{-}FuelOrganics}}$	Total PM EI by Mode
Idle	86.3	49.0	20.6	155.9
Approach	67.6	49.0	90.0	206.6
Climb-out	161.7	49.0	32.7	243.4
Takeoff	161.2	49.0	32.2	242.4

Table 6. Values of EIPM for the JT8D-217 Series Engine (mg/kg fuel)

5. Uncertainties

As its title suggests FOA3.0 is an approximation. The PM ad hoc group of CAEP Working Group 3 has endeavoured to make the methodology as accurate as possible. However, the user should be aware that not all physical concepts are well understood and data for many of the parameters are sparse. This leads to uncertainties in the estimation methodology including:

- Lack of data in the ICAO Data Bank, particularly:
  - SN.
  - Detail of whether the by-pass flow was included in the SN measurement.

- Reliance on average values of the specific engine's:
  - AFR.
  - Fuel sulphur content.
  - S^{IV} to S^{VI} conversion factor.
  - Combustor technology.

- Extremely limited data on volatile organics.

- No information on the effect of engine lubricants.

- Inaccuracies and measurement differences in reported data:
    - Annex 16 states that measured SNs can vary by ± 3.
    - Reported mass measurements vary considerably resulting in ranges of values.

The limitations of the Data Bank are being addressed by the engine manufacturers through CEAP WG3. Values of engine AFR are unlikely to be available as they are commercially sensitive. More confidence in the S^{IV} to S^{VI} conversion factor, volatile organics and the effect of engine lubricant will come with more experimental measurements and improved measurement techniques.

Since the inception of the FOA process, and it development into FOA3.0, the methodology has continued to evolve and the estimate accuracy improved. The FOA process is not static and will continue to evolve until measurements are sufficient that the approximation is no longer needed. In the interim, CAEP and specifically the ad hoc PM working group will continue to review available information to improve the methodology and the input parameters to the degree possible.

6. References

1. CAEP, "Particulate Matter Charactisation", Information Paper No. 6, Working Group 3-Technical Emissions, ICAO Committee for Aviation Environmental Protection (CAEP) meeting, February 2007.

2. ICAO, "Airport Air Quality Guidance Manual," Document 9889, ICAO PRELINIMARY UNEDITED VERSION - 15 April 2007.

3. NASA. Aircraft Particle Emissions Experiment (APEX). C.C. Wey, U.S. Army Research Laboratory, Glenn Research Center, Cleveland, Ohio. ARL–TR–3903. 2006-214382, September 2006.

4. Calvert, J.W. "Revisions to Smoke Number Data in Emissions Databank." Gas Turbine Technologies, QinetiQ. February 23, 2006.

5. Coordinating Research Council, Inc., Handbook of Aviation Fuel Properties, Third Edition CRC Report No. 635, Alpharetta, GA, USA, 2004.

6. IPCC, 1999, Aviation and the Global Atmosphere, Intergovernmental Panel on Climate Change, Cambridge University Press, ISBN 0 521 66404 7.

7. Katragkoue, E., S. Wilhelm, F. Arnold, C. Wilson, First gaseous Sulfur (VI) measurements in the simulated internal flow of an aircraft gas turbine engine during project PartEmis, ISSN 0094-8276, Geophysical research letters, November, 2003.

8. S. P. Girling, C. D. Hurley, J. P. Mitchell and A. L. Nichols, Development and Characterization of a Smoke Generator for the Calibration of Aerosol Emissions from Gas Turbine Engines, Aerosol Science and Technology, 13:8-19, 1990.

— — — — — — — —

Chapter 4

DISPERSION MODELING

Content

1. INTRODUCTION

In the emission inventory chapter, guidance on estimating the mass emitted for various pollutants was discussed. However, the total mass emitted does not account for mixing in the atmosphere which determines local concentrations or how much mass is mixed in the air at any given time. Additional modeling is required to estimate these local ambient concentrations.

A trace substance that has been released from a source into the free atmosphere will be transported by the mean wind field and dispersed by atmospheric turbulence. This process is referred to as atmospheric dispersion. **Dispersion** can be more rigidly defined[1] as "the scattering of the values of a frequency distribution from an average." It then follows that **atmospheric dispersion modeling** is the mathematical simulation of the scattering or mixing process in the ambient atmosphere. The trace substances most often evaluated are regulated atmospheric pollutants and were delineated in the emission chapter for airport sources. In an airport-related dispersion calculation, the atmospheric mixing of these trace substances or pollutants that are emitted from local sources is modelled based on scientific principals and the resulting concentration distributions (usually near the ground) are predicted. The results, or predicted atmospheric concentrations, form the basis for local air quality (LAQ) impact studies and are used to show compliance with required regulations and/or standards.

This chapter presents the needs for dispersion modeling in the vicinity of airports, provides a brief overview of dispersion models, summarizes typical practices that occur during atmospheric dispersion modeling at airports, and examines how predicted concentrations are used to estimate impacts. The chapter has been laid out to follow the procedure established in the emission chapter. That is, the required modeling will be discussed in a simple, advanced, and sophisticated approach.

2. EXTERNAL REQUIREMENTS AND DRIVERS

This section discusses the need for Dispersion Modeling and the external drivers that both cause and affect this need. As described in detail in Chapter 1: Regulatory Frameworks and Drivers, air quality assessments for proposed actions at airports are often necessary to comply with:

- Worsening air quality leading to reduced margins against existing regulations;
- Increased awareness of health impacts, leading to the production of new regulations, including the addition of new pollutant species;
- Development constraints resulting from limitations imposed by the need to meet air quality standards;
- Increasing public expectation regarding air quality levels;
- Public relations exercises carried out by airport and environmental lobbies; and,
- Legislative requirements of the various countries and regions.

Emission modeling to meet these requirements has been previously discussed. Emission modeling, a prerequisite to dispersion modeling, allows the change in emissions to be reviewed temporally and spatially. However, direct impacts are more related to the ambient concentrations and not just the mass of emissions emitted. Ambient air quality standards, evaluation of real impacts, and health impacts are better evaluated by the use of ambient concentrations than with mass emitted. As previously described, atmospheric mixing of emissions results in ambient concentrations most often used to determine local impacts. Measurements, described in Chapter 5 of this guidance, can be very costly, only define the concentration at a point in space for each measurement, and do not readily reveal the fractional contribution from each contributing source. Dispersion modeling allows the evaluation of local air quality to be done at a reasonable cost. Regardless, the need for dispersion modeling is to determine the ambient mixing as a part of the overall analysis process.

Beyond the evident need for dispersion modeling, ordinances or legislation often mandates the estimation process be used. The regulations resulting from these legal requirements may also specify how the dispersion modeling must be accomplished or how variables are considered. The analyst is prompted to review any related requirements to insure the process occurs as mandated.

3. GENERAL DISPERSION CONCEPTS

This section provides a brief overview of the basic physical concepts included in dispersion modeling and the process required. References are included to allow interested parties to go deeper in exploring these concepts than presented here. The understanding of how the models work should lead to more appropriate use of the models.

When a trace element or pollutant is emitted from a source, the final fate is determined by the characteristics of the pollutant, source characteristics, atmospheric motion, and local topography. Each of these parameters plays an important role in the local concentrations. A pollutant that is released in its final form is called a **primary pollutant.** Primary pollutants that are very slow to react with other gases in the atmosphere are called passive pollutants. Primary pollutants such as carbon monoxide (CO) are often called inert because of the very long reaction time and residence time in the atmosphere.

Secondary pollutants are formed in the atmosphere when the original precursor emitted undergoes chemical reactions or other conversion processes in the atmosphere and forms a new pollutant. The pollutant is termed secondary since the final composition is not as released from the source. Ozone (O_3) is a secondary pollutant.

The pollutant source affects the local concentrations due to the location of the release, the total mass flow rate, and the dynamics of the exhaust air due to the effect on the atmospheric dispersion in addition to the atmospheric motion. Atmospheric motions determine the overall direction the emissions travel and are primarily responsible for the mixing with the ambient atmosphere (**dispersion**), thereby creating a pollutant 'plume' (or 'puff'). The direction of the plume is determined by the large scale motion such as the mean wind flow while mixing is more related to small scale eddies in the flow referred to as **turbulence**. Likewise terrain characteristics and local building structures will have an effect on local area concentrations due to changes in the wind patterns and the generation of turbulence. All of these parameters affect atmospheric dispersion and lead to a three-dimensional, generally time-dependent concentration distribution of the emitted trace substance (pollutant). Likewise other substance-specific processes may have an effect such as dry and wet deposition.

The quantities that determine atmospheric dispersion resulting in a local concentration can be grouped as follows:

- Q1 Source parameters (location, shape, dynamics of the exhaust air);
- Q2 Emission parameters (emission strength of each trace substance for each source);
- Q3 Substance parameters (e.g. conversion or deposition properties);
- Q4 Atmospheric parameters (e.g. wind speed, wind direction, turbulence properties, and temperature); and,
- Q5 Terrain parameters (e.g. surface roughness, terrain profile, obstacles).

Not all of the above parameters are independent and most of the parameters are time-dependent. It is evident that the parameter set includes additional information than was required for emission calculations, even when emission allocation has been conducted as described in Chapter 3.

At airports, the relevant sources can be grouped as follows:

- S1 Aircraft, including Auxiliary Power Units (APUs);
- S2 Aircraft Handling Sources (e.g. Ground Support Equipment (GSE), aircraft fueling, airside vehicles);
- S3 Stationary and area sources (e.g. power plants, fire training); and,
- S4 Airport access traffic (e.g. landside motor vehicles).

The dispersion methodologies used are of course only for those sources directly included in the model. Regional or background contributions also add to the total local concentration to produce the total concentration. The total concentration is needed to compare to the applicable criteria or standards. These background sources can be substantial and come from sources at varying distances from the airport. How background sources and the resulting concentrations are accounted for needs to be considered based on the spatial resolution of the modeling area and data sources to be used such as long-term ambient monitoring stations. This stands in contrast to noise assessments, where the airport contribution is usually by far the dominating component. To account for the overall concentration the background concentration must be added to the concentration predicted by the models. This results in:

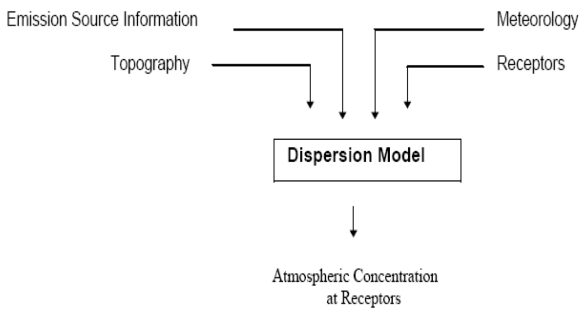
$$c_t = c_s + c_b \qquad [4.1]$$

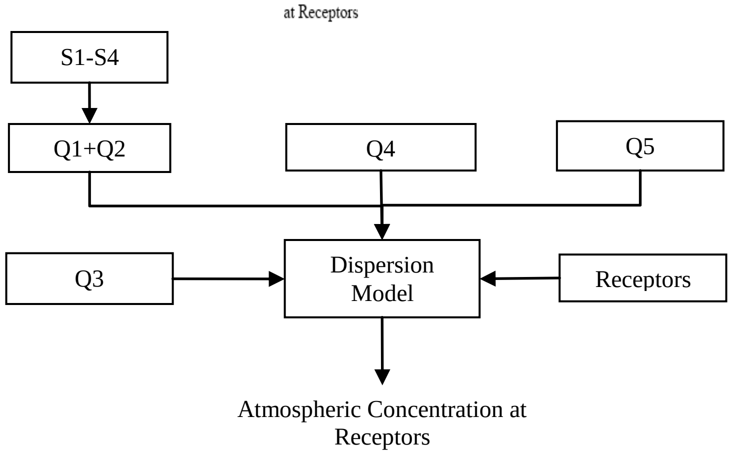
Where: c = concentration with the subscripts t, s and b representing total, source, and background, respectively.

The summation in Equation 4.1 represents the concentration at a point in space from all sources and is the value that is compared to applicable ambient air quality standards. Of note is that concentration, c, is pollutant specific. That is, pollutants of different species cannot be added.

Figure 4.1 shows an a) an overview of the modeling process and b) the detailed steps required.

a. Process Overview





b. Detailed Breakdown of Atmospheric Concentration Due to S1 – S4

Figure 4.1. Inputs and Outputs of Dispersion Modeling.[2]

Several approaches to dispersion modeling have been applied at various airports around the world to predict local concentrations. As the science continues to evolve, so will the airport models. As such, this chapter will concentrate on the common methodologies currently used rather than on specific models.

The actual formulation for these models may vary. To assist the reader in a more comprehensive understanding of dispersion model methodologies, model formulations are briefly discussed in Annex A. Computer models in commons use for airport dispersion modelling are listed in Annex B.

4. REQUIRED MODEL INPUTS

This section provides information on variables needed to perform a dispersion analysis. While this is a general overview to provide understanding for the reader, variables required will vary by modeling effort (simple, advanced, sophisticated) and the specific model used. Additionally, each airport is unique and this large variability, the differences in the availability of data, and the desired final product also result in different data sets for each airport.

4.1 Emission Source Information

A brief overview of the information that will be needed to complete the concentrations analysis is included in this section.

4.1.1 Airport Emission Sources

Air pollution sources at airports are many and varied. In order to perform concentration modeling, for each source studied, the emission strength for each of the modelled substance must be available. A detailed description on the emission sources found at an airport is given in Chapter 2 of this guidance manual.

4.1.2 Airport Temporal and Spatial Considerations (e.g., taxiways, runways, gates)

When performing an emission inventory, spatial and temporal allocations are not always required or completed. However, spatial and temporal allocations are of prime importance during dispersion modeling since local concentrations will be calculated. These local concentrations depend upon the distance to a source and its time of operation. This requires not only the emission data, but explicit detail on when and where and in which way the emissions occur. Airport spatial and temporal variation was previously discussed during emission allocation in Chapter 3.

Dispersion modeling often relies on Cartesian coordinates (x,y,z) where x and y are the horizontal distances and z is the vertical distance from an established datum point. A common practice, for easy transfer to maps, is to set the positive y axis is in the north direction. A thorough understanding of the airport operation is required for detailed dispersion modeling (see Chapter 3). For all but the simple approach, all source locations must be established (see Chapter 3) and for dispersion modeling, a new component, the receptor must be added as discussed in Section 4.4. The receptor location must be exactly specified, as with the source, leading to the use of coordinates such as the Cartesian coordinate system. The defined receptor location determines where the concentration will be predicted using the dispersion models. This is most often at locations of frequent human use. Some dispersion models are based on specific time periods since their dispersion parameters change with time after release. This is often an internal parameter, transparent to the user, and can be adapted based on the output needs to compare to ambient air quality standards.

4.1.3 Emission Factors

Emission factors are needed to determine the rate of release for emissions from each source. Emission factors are both source and pollutant specific. The reader is referred to Chapter 2 for a complete discussion of emission factors.

4.2 Meteorology

Meteorology is an essential input for the dispersion calculation. Without an input for the local weather, it is not possible to perform dispersion modeling except in the simple cases. For all modeling of any sophistication, the parameters for the planetary boundary layer (PBL) must be known. As with other variables, the degree of sophistication of the modeling process can vary but a general listing of needs is discussed here. Additionally, some common sources for this data are listed in Annex C.

4.2.1 Wind Data

The horizontal wind speed (velocity) and direction generated by the geostrophic wind component and altered by local surface characteristics and other parameters such as terrain is of primary importance in all but the simple case. In the advanced and sophisticated approach, local climatology must be established in more detail and may include wind data from multiple elevations and/or vertical wind gradients. Often this historical data is available from existing records (see Annex C). The wind speed and direction will vary by surface characteristics and topography, local buildings, surface cover, and nearby influences such as large bodies of water, to establish a suitable wind field depending on model requirements.

4.2.2 Turbulence and Atmospheric Stability

The **atmospheric stability** can be simply defined as the turbulent status of the atmosphere and has a significant effect on the dilution rate of pollutants. Turbulence refers to the small motions of the atmosphere, generally circular in nature and referred to as eddies. These eddies vary dramatically in size depending on atmospheric stability. Small eddies can “rip” apart the plume and cause mixing with the local air while large eddies tend to move the entire plume.

Turbulence can be characterized in several ways including empirical methods (e.g., the Pasquill-Gifford Stability Classes), the flux Richardson number, the gradient Richardson number, or the Monin-Obukhov length. While each requires different inputs to determine, the basic meteorological information needed is wind speed by height (wind shear), temperature by height (lapse rate), wind velocity fluctuations, and surface characteristics.

Turbulence is often broken into the categories of stable (vertical mixing of pollutants is hindered), neutral (vertical motion of the atmosphere is nether hindered or enhanced), and unstable (vertical motion of the atmosphere is enhanced).

4.2.3 Upper Air Data

In the advanced and complex analysis it is recognized that the atmospheric conditions change with height. To account for this change, meteorological data at greater heights (up to some hundred metres) than surface data are often used, although some models can approximate the change with height based on surface data and use boundary layer parameterization. If the measured data are used, these data come from acoustic soundings, release of balloons with instrument packages, and reports by aircraft.

4.2.4 Temperature

The ambient temperature has an effect on the rate of chemical reactions and may be needed in the sophisticated approach. The change of temperature with height (lapse rate) may be needed by models to assist in determining atmospheric stability and could be needed for both the advanced and sophisticated approach.

4.2.5 Cloud Cover

Cloud cover has the direct effect of changing the albedo and is often used indirectly for atmospheric stability in the advanced approach.

4.2.6 Derived Parameters (Model Specific)

Many parameters may be important depending upon the model chosen (e.g., sensible heat flux, surface friction velocity, convective velocity scale, vertical potential temperature gradient, Monin-Obukhov length, and the Bowen ratio). Often these parameters can be derived from the basic meteorological data listed above. The parameters are not described here but if not computed directly by the dispersion model selected, the user should take great care to understand these parameters and how they may be derived.

4.3 Surface Roughness

Different types of surfaces change the frictional characteristics of the surface and affect the vertical wind profile and the turbulence characteristics. For airports this is often a vegetative flat relief near the runways. But the location and height of buildings such as the terminal, tree lines, and for some airports significant changes in the surface profile must all be determined. After this determination, charts may be used to determine the value of the surface roughness parameter (z_0) to be included in the model. Table 4.1 shows an example of values that can be selected. Of note is that this is a parameter and not a true length of the objects on the surface.

Table 4.1 Surface Roughness Length, z_0, for Typical Surfaces[3]

Terrain Description	Z_0 (m)
Water	0.0001
Grassland (winter)	0.001
Grassland (summer)	0.1
Cultivated Land (winter)	0.01
Cultivated Land (summer)	0.2
Swamp	0.2
Desert Shrubland	0.3
Deciduous Forest (winter)	0.5
Deciduous Forest (summer)	1.3
Coniferous Forest	1.3
Urban	1.0 – 3.0

4.4 Receptor Information

A receptor is a location in space that may represent human occupation or simply a location of interest. Receptors can also simply be a predetermined grid of a specific size, centered on an established airport reference point. Airport receptor locations may be defined on or off of the airport. These are chosen by a review of the airport with particular interest in locations where normal human activity occurs or in other locations for example nature reserves. The choice of receptor locations will result in modelled concentrations at these points used to determine the overall impact at that location.

4.5 Background Concentrations

As previously discussed (Equation 4.1), background concentrations are due to sources not considered during the modeling process. These concentrations must be added on a pollutant specific basis to the model results to obtain the total concentration of any pollutant. The background concentrations are generated by nearby roadways, industry, commercial operations, residential areas, and long-range transport. The background concentration is most often determined by long-term measurement stations in the area since the sources are too numerous to be modelled during an airport evaluation. The averaged upwind concentration to the airport is often used and may be temporally allocated to account for diurnal changes in the other local sources. Depending on the pollutant, significant percentages of the overall (measured) concentrations may be from background concentrations sometimes brought into the study area from large distances.

4.6 Atmospheric Chemistry

As previously mentioned, pollutants may react with other components in the atmosphere after being emitted by the source. This causes a change in precursors and creates new pollutants. This is particularly important for aircraft emissions where secondary gas and particulate matter pollutants are created. This is an advanced topic and will most often be built into the model used or may even be ignored depending upon the scope of the study. Chemical reactions are always ignored in the simple approach defined here. In the case where atmospheric chemistry is not explicitly considered, ratios based on historic data can be applied and this is defined in this document as the advanced approach. For example, the ratio of NO to NO_2 is important. Historic data may provide a typical ratio. This ratio can then be applied to the NO_x prediction ($NO + NO_2$) which is predicted by models without chemical algorithms. If not performed by the model, speciation of hydrocarbons may also be approximated in this manner based on the total hydrocarbon prediction and historic data.

Chemical reactions proceed at different rates and are affected by ambient concentrations, transport time, and ambient conditions with all being considered in the sophisticated approach. The time for the reaction to occur is different for each pollutant and the reaction rate is necessary for dispersion modeling of reactive pollutants.

5. DISPERSION CALCULATION

Annex A contains a very general overview of the dispersion methodologies while Annex B lists models commonly used for airport analysis. The purpose of this section is not to provide detailed directions on the use of these methodologies or concepts and the reader is directed to the appropriate texts or user manuals for the specific methodology/method chosen. The fundamental approach for simple, advanced and sophisticated is described in this section. The choice of which method is best suited for the analysis will depend on the data available and the desired use of the results.

5.1. Analysis and Level of Effort

As the analyst proceeds from the simple, to the advanced, and to the sophisticated approaches, the data requirements increase as well as the analysis time. However, the accuracy increases with the additional effort required if the input data is of good quality. Simple approaches should be conservative in nature while the advanced and sophisticated approaches will provide results that permit the impact analysis to be more realistic. Table 4.2 shows the input variables that may be needed if the simple, advanced or sophisticated approach is chosen. Exact needs are determined by the model selected.

Table 4.2 Input Data Needed Depending Upon Approach Taken

Key Parameters	**Simple Approach**	**Advanced Approach**	**Sophisticated Approach**
Emissions	As described in Chapter 2 of the guidance		
Spatial resolution	For Case 1: No differentiation; airport as one "emission bubble". For Case 3, very large mesh size using single source location such as runways.	Defined receptor positions with spatial resolution on a coarse grid (e.g. not less than 500m mesh size)	Defined receptor positions with fine grid on a 10 by 10 m mesh size, but not more than 500 by 500 m mesh size
Temporal resolution	Annual total	Monthly or daily resolution	Hourly or smaller resolution
Meteorological	1. No weather data. 2. Wind speed is 1 m/s. Wind direction, very stable atmosphere for ground level sources, and no plume rise is used to predict a conservative estimated (often referred to as “worst case”) concentration calculated at the receptor. Mixing height not considered.	Climatological data for multiple parameters ranging from an hourly to daily average Turbulence as a single parameter such as a stability classification generally from only wind speed and cloud cover considerations. Average mixing height for area, generally assumed to be 914 meters (3000 feet).	Detailed climatological data on a small time scale including upper air and specific mixing height data. Multiple derived parameters requiring additional data such as cloud cover and temperature gradients.

Surface Roughness	Assume all area is flat and grass.	Consideration of major topographical features.	Consideration of topographical features, ground cover, and local buildings.
Receptor Information	General locations at ground level.	Specific locations at ground level.	Specific locations with varying horizontal and vertical locations.
Background Concentration	1. Not considered. 2. Single value for airport area.	Single value for airport area.	Temporal and spatial considerations included.
Atmospheric Chemistry	None	Typical (analytical) transformation ratios from established studies.	Detailed reaction rate constants with consideration of local ambient concentrations of reacting chemical species.

The designation 1 in the simple approach refers to the rollback model approach while 2 is a conservative analysis often referred to as the "worst" case analysis.

It is again noted that many models will not support all variables or require very specific information and it is the responsibility of the analyst to determine which variables are required by any model.

5.1 Simple Approach

The simple approach can be thought of in two distinct ways: 1) use of a rollback model in which airport data is lacking except for the overall change in operations; and, 2) a simplistic so called "worst case" analysis. As in Chapter 2 for emissions, the simple approach is only recommended when limited data are available or for initial assessments.

5.1.1. Rollback Approach

The rollback approach is the most simple and requires the least data and as such can be performed very quickly. It is also represents the greatest error. In this approach, which is not actually dispersion modeling, known emissions and concentrations are scaled according to overall changes in the aircraft operations. This assumes all other sources grow or decrease at the same rate as the aircraft operations. Equation 4.2 represents the idea numerically:

$$\Delta_2 = \Delta_1 (O_2 / O_1) \quad [4.2]$$

Where: Δ_2 = Total Emissions or Local Area Concentration at Time 2
Δ_1 = Total Emissions or Local Area Concentrations at Time 1
$O_{1,2}$ = Aircraft Operations in LTOs for time 1 and 2, respectively

5.1.2. Worst" Case Analysis

In this analysis, wind speed is assumed to be the smallest value that provides reasonable answers in a model, typically a constant 1 m/s. The wind is also assumed to be from a direction that produces the greatest concentration at the receptor location. The atmospheric stability is considered to be very stable for ground level sources and the mixing height is not considered. Background concentrations are assumed to be a single, conservative value. Use of these parameters results in a so-called "worst case" analysis in that in reality the concentrations would rarely, if ever, be this high. These assumptions lead to the logic that if criteria or standards are not shown to be exceeded in this conservative estimation where predicted concentrations are most likely at a level greater than would normally occur, then there is not a substantial impact. Simple models can be used and as such this method can be coded into a spreadsheet (such as the use of the Gaussian formulation included in Annex A) or graphs and tables may be used. Simple computer models may also be used. The advantage is only a small set of data is needed and quick results. The disadvantage is a very conservative prediction that overestimates impacts.

Advanced Approach

In this approach, computer coded models are a must. Specific models may be required by the reviewing agency, some models are available in the open domain, or proprietary models may be purchased. Each model will have a user guide and most will have a technical manual for the interested analyst. The analyst must completely review the user manual and be sure of input. The old adage "garbage in equals garbage out" is very true in this case and the result, even for the most complete model is only as good as the input data used. Some models may include an interactive graphical user interface (GUI) to allow input more easily included. If not, input files will have to be created. Some models may have the needed emission factors (or in the case of aircraft emission indices) included to also make input easier. In these cases the emission inventory may also be accomplished directly in the model. If this information is not included, the emission inventory will have to first be completed externally. Temporal and spatial allocation may occur at the emission inventory phase or postponed until the dispersion analysis.

These models may be the same as in the sophisticated approach with the difference being a greater use of default values for input variables, less complete operational data, non-varying background concentrations, and a lesser degree of spatial and temporal definition. Models inputs contain a large amount of "default" values, that is typical values for airports but not actual for the defined airport. Typical models used in the advanced approach for modeling in the vicinity of airports include ALAQS-AV, AEDT/EDMS[4], ADMS-Airport[5], and LASPORT[6].

Sophisticated Approach

This approach requires the most extensive data collection effort to define inputs. Default values are replaced with real data and this is especially true of meteorological input. Operational data is very complete with a much greater emphasis on spatial and temporal resolution. The models may be the same as in the advanced approach but with the actual data and a much greater use of options. Typical models used in the sophisticated approach for modeling in the vicinity of airports include ALAQS-AV, AEDT/EDMS, ADMS-Airport, and LASPORT.

Hybrid Approach

As with emissions, the three basic approaches can be mixed according to need and available data. The simple approach, because of the large simplifications that are made, does not lend itself to the hybrid approach except in very special situations. The advanced and sophisticated approaches are often mixed. This is especially true when the same model is used first with a high number of defaults input values for a high level assessment and then refined to allow more detailed modeling.

6. MODEL OUTPUTS

Each model has different outputs but some are common to all models. The first is an echo file of the input data when computer models are used. This is an important component of the output because it allows the user to check the input data to 1) be sure of the accuracy of input; 2) make sure the model has interpreted the data input correctly (very important for fixed field inputs); 3) evaluate derived parameters by the model which will be reported with the input; and, 4) allow the analyst to store the results and later understand the inputs used.

The most important output of course from all models is the calculated concentrations. The concentrations will be output as a certain time average (e.g. annual mean or series of daily means), possibly supported by some statistics (e.g. percentiles or exceedance frequencies) or even by complete time series (e.g. hourly means at given receptor points). The units of the concentrations will typically be either parts-per-million (ppm) or micro-grams-per-cubic-meter ($\mu g/m^3$). In the case of particulate matter, only $\mu g/m^3$ is valid. The calculated or predicted concentrations including background should then be compared to the ambient air quality standards or criteria with the correct time frame and units.

Some models may also include graphical outputs to assist in determining problem areas or to allow a visualization of changes, for example during mitigation modeling. In the sophisticated approach multiple derived parameters will also be available in the output.

7. MODELING APPLICATION AND INTERPRETATION OF RESULTS

The analyst should be aware of the fidelity of the results. This depends on the model used, the accuracy of the input data, and any assumptions applied.

Uncertainty in Dispersion Modeling

Since air pollution dispersion models vary from the simple to the very complex, there is a large difference in the uncertainty from model to model. Hanna[7] points out that total model prediction uncertainty is a combination of parameters including: model physics errors, natural or stochastic uncertainty, and data errors. As the number of parameters increases, the natural or stochastic uncertainty decreases and the model's representation of the physical reality becomes better. This leads to more complex models and a greater need for high fidelity input data. However, as the number of input parameters increases, the input data errors may increase. Poor input data could cause the more complex model outputs to be equal or even inferior to using more simplistic models. In addition, model adjustments based on limited data sets can lead to additional error.

This makes it extremely difficult to quantify the uncertainty. Models may perform well in predicting the maximum occurrences but may do poorly when trying to predict concentrations in time and space when compared to measurements.

Limit values and required model results often refer to statistical quantities like percentiles, long-time averages like annual means, or maximum concentrations independent of their specific occurrence in time or their accurate location. A model may yield reliable results with respect to these quantities even if it shows poor performance in a point-by-point comparison, for example with a measured time series at a given location.

Verification Based on Measurements

Complex dispersion models are applied in form of computer programs. In view of quality assurance it is required to verify and validate such programs. The verification checks whether the program correctly implements the mathematical formulation (algorithms) of the model. The validation then checks how well the model respectively the program describes the reality, usually by a comparison with measured data sets.

For the validation it is important that these data sets are sufficiently complete, i.e. that the validation test can be performed with the smallest amount of additional assumptions. If assumptions are required or if assumptions have been implemented in the model or the program, it is of importance whether they are based on general grounds or adjusted for example to a specific airport or situation. With regard to input data, complex models are usually better able to account for specific airport details and are thus more flexible for validation against measured data.

Comparison to Applicable Standards and Criteria

The term impact has been used throughout this chapter. This is because impacts are most often evaluated by comparing the predicted concentrations from the dispersion models to standards and/or criteria which most often are time-averaged concentrations based on health effects. The use of these standards has been addressed in earlier chapters and will not be repeated here. However, it is important to realize the connection between dispersion modeling and impact assessment. Results from the emission inventory do not allow this direct impact analysis. It has also to be considered that usually only by conducting dispersion modeling of all contributing sources plus the inclusion of all background concentrations will results be produced that may be directly compared to applicable standards. Modeling uncertainties must still be considered with respect to reporting direct impacts.

Use of Multiple Runs During Mitigation Considerations

Both the emission inventory and the dispersion analysis results may be used for mitigation purposes. The big difference, as noted in the preceding section, is that the dispersion analysis results that compare the existing case and multiple future scenarios allows evaluation of changes in local area concentration and directly the changes in impacts that are health related.

Future Advancement in Models

As the understanding of the emission and dispersion of airport-related source systems increases, models will be improved to reflect and incorporate these advancements.

In addition to model development, combination of microscale (the ones discussed here) and regional modeling are occurring to allow evaluation of the impact at larger distances from the airport and a more detailed consideration of background concentration at the airport.

As advancements occur, agencies and airport authorities will be faced with the need to evaluate and implement modeling practices that provide the best impact analysis for the airport. As such, this field is dynamic and any documents such as this one will need to be evaluated over time for possible updating.

8. REFERENCES

[1] Merriam-Webster Online Dictionary. http://www.merriam-webster.com/dictionary/dispersion.

[2] Draper, J., S. Webb, Augustine, Pernigotti, J. Plante, Liang, Air Quality Procedures For Civilian Airports and Air Force Bases, Appendix I: Dispersion Modelling, FAA-AEE-97-03, Arlington, VA., April, 1997.

[3] Turner, D.B., Workbook of Atmospheric Dispersion Estimates, An Introduction to Dispersion Modeling, 2nd Ed., Lewis Publishers, Boca Raton, FL., 1994.

[4] U.S. EPA, AERMOD, AERMIC Dispersion Model, http://www.epa.gov/scram001/7thconf/aermod/mod-desc.txt, last visited May 31, 2005.

[5] CERC, ADMS 3, http://www.cerc.co.uk/software/adms3.htm, last visited May 31, 2005.

[6] Janicke Consulting, LASPORT 2.0, A program system for the calculation of airport-induced pollutant emissions and concentrations in the atmosphere, Germany, 2009http:///, http://www.janicke.de/en/lasport.html, last visit September 23, 2009.

[7] Hanna, S.R., Plume dispersion and concentration fluctuation in the atmosphere, Encyclopedia of Environmental Control Technology, Volume 2, Air Pollution Control, Gulf Publishing Company, Houston, Texas, 1989.

[8] Pasquill, F., Atmospheric Diffusion, Van Nostrand, New York, 1962.

Dispersion modeling is a relatively new science and development is continuing. In 1895, Reynolds produced a paper discussing laminar to turbulent flow in pipes and has been considered by some to be the starting point of dispersion modeling. Taylor produced one of the first papers on turbulence in the atmosphere in 1915 and in 1921 produced the 'Taylor theory of turbulent diffusion' which provided a basis for describing dispersion with constant eddy diffusivity. Development continued and in 1962, Pasquill published the landmark book "Atmospheric Dispersion"[8]. This work summarized what had been done to that time and is the basis of modern Gaussian plume models based on the horizontal and vertical spread of the plume being determined experimentally as a function of atmospheric stability and distance; the now well known sigma values. The sigma values are in reasonable agreement with the Taylor theory.

There are different types of dispersion modeling methodologies for a dispersion calculation, with different features and capabilities. In the 1960s work on dispersion modeling continued to expand and formalize the dispersion modeling process including plume rise considerations. This resulted in the basis of the Lagrangian (moving coordinate axis) and Eulerian (fixed axis) modeling we know today. The science has become an accepted approach to prediction of concentrations of pollutants in the vicinity of airports which is directly connected with impact on public health and welfare. Performance of dispersion modeling requires key variables to be carefully assembled and various methodologies have occurred. A very brief description of each is included here.

A.1 *Gaussian Formulation*.

The Gaussian formulation is still used more than any other approach. This Lagrangian approach assumes downwind dispersion to be a function of stability class and downwind distance and applies the Gaussian probability density function to account for plume meandering and diffusion. It was released in various forms by the U.S. EPA as part of the UNAMAP series in late 1960s and developments still are on-going worldwide. It can be applied to plumes or individual puffs and as such provides needed flexibility for local air quality modeling. It has been adapted for point, line and area sources. In its basic point source form, for a plume, the concentration (c) is predicted with the following mathematical expression:

$$c(x,y,z) = \frac{Q}{2\pi u \sigma_y \sigma_z} exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)\left\{exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right) + exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right\}$$

where: Q = source strength
u = wind speed
h = stack height
σ_y, σ_z = horizontal and vertical dispersion coefficients

Of note is that x, the distance downwind, is included implicitly in the horizontal and vertical dispersion coefficients that increase with downwind distance.

More recent Gaussian model formulations have used a bi-Gaussian distribution in the vertical to better account for vertical mixing in convective conditions. This results in more accuracy but also a more complex model.

A.2 Eddy Diffusivity based on Mass Conservation Formulation.

In this Eulerian approach, the approximate solution of the mass conservation governing equations are used with simplifying assumptions that relate turbulent fluxes $\langle u'c' \rangle$ to concentration gradients, $\partial c/\partial x_i$ by including an eddy diffusivity term, K_i. This results in:

$$\langle u'c' \rangle = -K_i (\partial c/\partial x_i)$$

This approach is used for widely or uniformly distributed pollutants where large individual plumes are not dominant. This occurs for such pollutants as carbon monoxide. This approach has been applied in regional modeling in the form:

$$\frac{\partial c_i}{\partial t} + u_x \frac{\partial c_i}{\partial x} + u_y \frac{\partial c_i}{\partial y} + u_z \frac{\partial c_i}{\partial z} = \frac{\partial}{\partial x}\left(K_x \frac{\partial c_i}{\partial x}\right) + \frac{\partial}{\partial y}\left(K_y \frac{\partial c_i}{\partial y}\right) + \frac{\partial}{\partial z}\left(K_z \frac{\partial c_i}{\partial z}\right)$$

$$+ R_i\left(c_1, c_2, \ldots, c_n\right) + E_i\left(x, y, z, t\right) - S_i\left(x, y, z, t\right)$$

where: u_x, u_y, u_z = velocity
c_i = concentration of i^{th} species
R_i = chemical generation rate of species i
E_i = emissions flux
S_i = removal flux

A.3 Box Model.

The box model is a simplistic mathematical representation of a defined, well-mixed volume of air (the box) that includes inputs and outputs into the volume. Since the box is well mixed, the output concentration is equivalent to the concentration inside the box. Multiple boxes may be used in the horizontal or vertical with the output of one box representing the input of the next in a grid approach. Chemical reactions can be considered in each box. This allows the mass conservation formulation to be used for each box in this Eulerian method.

A.4 Trajectory Models.

These models, based on the Lagrangian approach, provide an approximate solution by using the governing equations of mass conservation and a coordinate system that moves with the average wind velocity. This approach implies that parcel integrity is reasonably maintained for the length of time of model simulation and assumes that horizontal wind shear, horizontal turbulent diffusions and vertical advective transport are negligible. This model is not generally accepted for general use for regulatory applications in the U.S.

A.5 Mass and Momentum Models.

In this type of model, governing equations of mass and of momentum are applied using first order principles. For example, approaches may begin with the fundamental Navier-Stokes equation and include turbulence based on Reynolds averaging. The result is more scientifically rigorous with complex procedures that avoid the K-theory simplification but are often computer and data intensive and specific to a particular case. As such, this category of models tends to be more research oriented and not in common use.

A.6 Lagrangian Particle Models.

In contrast to Gaussian models which are based on an analytical solution of the classical dispersion equation and Eulerian models which solve this equation numerically, Lagrangian particle models simulate the transport process itself.

Out of the huge number of particles (gas, aerosol, dust) usually emitted by a source, only a representative, small sample is considered. The sample size is typically of the order of some million particles, depending on the problem and available computer resources. The trajectory of each of these particles is calculated on the computer by a stochastic process (Markov process in phase space). From these trajectories the three-dimensional, time-dependent, non-stationary concentration distribution is derived.

The core of a Lagrangian particle model, as for example specified in the guideline VDI 3945/3 (English/German, see www.vdi.de), does not contain tuneable parameters. It relies on meteorological parameters that can be determined without dispersion experiments. Time scales typically range from some minutes to one year with a time resolution down to some seconds, spatial scales range from some metres to some 100 kilometres.

Increased research and application to atmospheric physics started about 20 years ago and Lagrangian particle models have become more widely used with increased computer speeds and memory storage. Today the technique is routinely applied in air quality control.

A.7 Plume-in-Grid Approach.

This method is a hybrid between the Lagrangian and Eulerian approaches. The Eulerian approach is adapted by using trajectory models or Gaussian dispersion techniques to preserve trace specie concentration to overcome the deficiencies regarding instant mixing of pollutants in the grid.

A.8 Closure Models.

In Eulerian models, vertical diffusion must be addressed. Two different turbulence closure schemes are typically used: local closure and non-local closure. Local closure assumes the turbulence is similar to molecular diffusion while non-local closure assumes the turbulent flux to be similar to mean quantities at different layers and an exchange of mass is allowed. Closure models are often discussed in terms of first-order for prognostic equations for the mean variables (i.e., wind or temperature) or higher order models which are more complex. This type of modeling is closely related to eddy diffusivity models previously described.

A.9 Statistical Models.

This idea is based on statistical analysis of ambient pollutant measurements and other emissions information. This approach is best used when detailed source information is available, as these models have difficulty in applying results as location parameters change. One subset if this type of modeling is receptor modeling which has been used to predict particulate matter in the U.S. and in the U.K. Receptor modeling uses multivariate statistical methods to identify and quantify the apportionment of air pollutants to their sources.

In sum, this partial listing of procedures is meant to provide a background for the discussion of dispersion modeling allowing the analyst to better understand the process.

ANNEX 4B. Commonly Used Dispersion Models in the Vicinity of Airports

The purpose of this annex is not to recommend any particular model or to show detailed information on any model. The analyst is expected to choose the appropriate model based on legislative requirements, data available, and intent of use.

Table B.1 shows computerized modeling packages that have been commonly used at airports. Of note is that there are many models that have been used and the table is not all inclusive.

TABLE B.1. Commonly Used Dispersion Models at Airports

Airport Air Quality Model	**Fundamental Type of Dispersion Model**	**Model Information**
AEDT/EDMS	Bi-Gaussian	Sponsoring Organization: United States Model Developer: Federal Aviation Administration
ADMS-Airport	Bi-Gaussian	Sponsoring Organization: United Kingdom Model Developer: CERC
ALAQS-AV	Bi-Gaussian / Lagrangian	Sponsoring Organization: France Model Developer: EUROCONTROL
LASPORT	Lagrangian	Sponsoring Organizations: Germany and Switzerland Model Developer: Janicke Cons.

Obvious in all of these reports are that no one modeling approach totally meets all current modeling needs, especially if cost, practicality and complexity are considered. This results in either multiple models being used and selected on a case-by-case basis or adaptations/simplifications of the selected model inputs.

The analyst should carefully review any legislative requirements, sources to be modelled, inputs needed for any specific model, and limitations of any model when selecting the appropriate dispersion model.

ANNEX 4C. Climatological Information Sources

Dispersion modeling using the Advanced or Sophisticated Approach requires detailed meteorological data. Care should be taken in selecting this data. Short term data may not accurately display trends and may not be representative of the seasonal variations, dominant wind patterns, or diurnal variations.

The World Meteorological Organization (WMO) (http://www.wmo.int/pages/index_en.html) includes:

> "more than 10000 manned and automatic surface weather stations, 1000 upper-air stations, over 7000 ships, more than 100 moored and 1000 drifting buoys, hundreds of weather radars and over 3000 specially equipped commercial aircraft measure key parameters of the atmosphere, land and ocean surface every day."

Information is available for multiple years and data bases were established prior to 1950.

The World Data Center for Meteorology with 52 centers in 12 countries (http://www.ncdc.noaa.gov/oa/wdc/index.php) represents a huge number of monitoring stations worldwide.

Individual countries may also maintain the required climatological data for a region or country. These include the British Atmospheric Data Centre (http://badc.nerc.ac.uk/home/index.html) in the U.K. and the National Climatic Data Center (NCDC) (http://lwf.ncdc.noaa.gov/oa/climate/climatedata.html) in the U.S. For example NCDC has directly downloadable surface data, upper air data, and other useful information in multiple formats. Of importance are the historical records over many years that helps to avoid errors due to incorrect input parameters. The data are available from the 1800s to the present for over 8000 locations in the U.S. and 15,000 worldwide stations depending upon the data needed.

Climatological data can be found at many universities world wide as well and often may provide unique data for a region. It is suggested the analyst explore this possibility of information.

— — — — — — — —

Chapter 5:

AIRPORT MEASUREMENTS

Table of Contents

Introduction

5.1.1 Airports are an important part of the economic infrastructure of the cities they serve; passenger and cargo activity at an airport support local air transportation needs. However as part of that infrastructure, airports are a magnet for many types of activities that contribute air pollution to the local area: aircraft, automobiles, ground support equipment, stationary sources, etc. Often responding to various objectives and requirements, airports and/or local authorities seek to obtain an understanding the contribution of airport-related pollutant sources to the local air quality. While modeling tools are available, some airport locations seek to quantify airport-related emissions through the conduct of actual air measurements. It is important that measurements conducted for airports comply with the appropriate measurement protocols. This chapter describes the various elements for ambient air quality measurements for airports.

Requirements and Drivers for Measurements

5.2.1 Chapter 1 of this guidance material describes the general local air quality regulatory framework and drivers influencing the aviation industry to provide information or undertake action related to air quality. Specific to ambient air quality measurements, numerous requirements and drivers influence the need for airport ambient air quality measurements to be conducted. Measurements are often conducted in order to meet legal obligations, as part of voluntary programs, or for model verification.

5.2.2 Legal Compliance: To comply with applicable ambient air quality regulations and accompanying standards or targets for particular pollutants, airports and in some place local authorities may be required to conduct ambient measurements. An airport or local authority might also be under the obligation (e.g. for baseline assessment or in the context of expansion projects) to perform measurement on a regular or irregular basis.

5.2.3 Voluntary Programs: For example, public and community concerns often trigger the need for measurements to obtain actual information about air quality in the local vicinity. Alternatively, an airport may voluntarily conduct measurements and report as part of their environmental policy and management activities.

5.2.4 In addition to public and community concerns, new scientific evidence or hypotheses may emerge that suggest initiating measurement campaigns at or around airports to seek clarifications or obtain further information.

5.2.5 Model Verification: Sometimes, model results are calibrated with measured results to determine the ability of a model to characterize current conditions with some degree of confidence. Once a particular model is verified for baseline conditions, it can be used with greater confidence to predict future scenarios accurately. This is particularly important when an airport is considering potential action (e.g., infrastructure development) and needs to analyze the potential impact of the action and any potential mitigation measures.

5.2.6 The major caveat associated with the model verification is the fact that the model usually predicts concentrations from one or several emissions sources but not necessarily from all contributing sources. In this case it might be difficult to compare modeled concentrations to measured values, and complex procedures have to be applied for the purpose of actually performing model verifications.

Measurement Plan

5.3.1 **Design Process of a Measurement Plan**

5.3.1.1 The measurement plan for local or regional air quality measurements is determined by external and/or internal requirements and the necessary resources available. The following main elements in a plan should be addressed (see also Figure 5-1):

1. Objectives and requirements for measurements (as described in section 2)
2. External factors
3. Measurement locations (with respect to the airport premises)
4. Measurement methods
5. Management planning

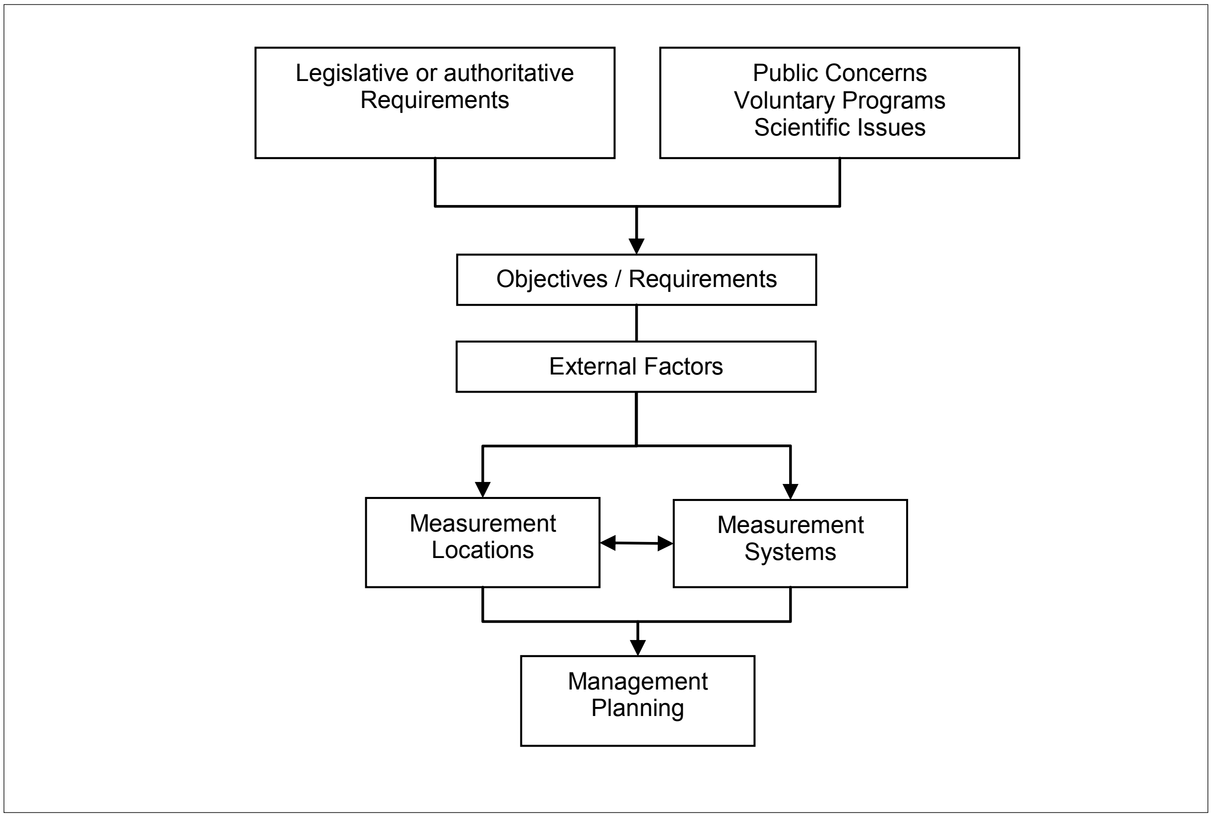


Figure 5-1: **Measurement Plan Elements**

5.3.1.2 The requirements and drivers for local airport air quality measurements are outlined in section

5.2. Following the external requirements, airports may have a single or multiple objectives for the measurements. Objectives can include the desire to obtain factual information on the actual ambient air quality concentrations at specific receptor locations for communication purposes or to establish long-term trend analysis to observe the development of air quality at the measurement sites in response to the emission developments.

5.3.2 External Factors

5.3.2.1 The key external factors to be considered in ambient air quality measurements are potentially existing measurement standards, recommendations and guidelines. If applicable, practicable, or available, local or national framework documentation for ambient air quality measurements should be used. This can range from general issues like measurement principles or quality assurance to prescribed measurement systems that have to be put in place.

5.3.2.2 In some cases, airports will have to bear the responsibility and costs for air quality measurements. To this end, the available resources, technical skills and budget may be factors that determine the possible scope of air quality measurements.

5.3.2.3 An air quality monitoring network may already be in place that is operated by local authorities or other entities. In this case it would be advisable to coordinate or even harmonise potential measurement plans to avoid duplication of similar or identical measurements or to avoid inconsistencies or even contradictions.

5.3.3 Measurement Locations

5.3.3.1 The objectives and requirements as described in section 2 will help determine the locations of monitoring stations. The generic measurement site selection plan in Figure 2 and Table 1 identify the various site characteristics and their relevance within the measurement concept. Air measurements should be conducted upwind and downwind from the airport/airport sources while at the same time striving to achieve a source distribution discrimination. To achieve source distribution discrimination, locations should be defined that are most likely dominated by a specific emission source, while other sources may contribute only marginally to the overall concentrations.

5.3.3.2 The following questions are associated with the choice of the measurement locations:

- What are the current (past) pollution concentrations of relevant species near the airport?
- Can airport induced impacts be - at least to some degree - singled out?
- What is the trend of the pollution concentrations?

5.3.3.3. A generic yet typical site selection plan is illustrated in figure 5-2 with each location described and justified in table 5-1. This site selection plan may vary from airport to airport, depending on the actual regional land uses, infrastructure, and development.

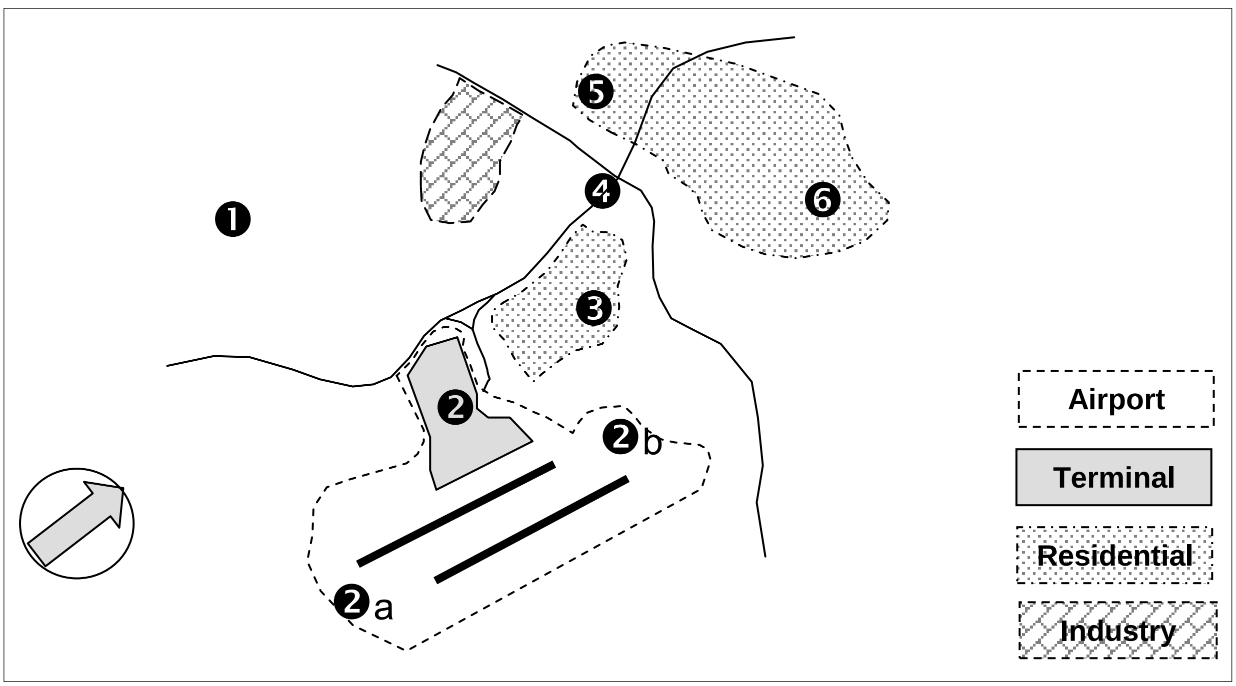


Figure 5-2: Generic Measurement Site Selection Plan (circled arrow: prevailing wind direction)

Table 5-1: Description of Generic Measurement Sites

Number	Description of Site	Justification
1	Background concentration site, undisturbed by any polluting activities	This station provides the background and baseline data for the region where the airport is located.
2	All stations (including a and b) are located within the airport area with intense airport activities. Optionally, stations are located directly upwind and downwind (and sideline) of the runways, often at the airport boundary.	It can be expected that these stations will most likely best reflect the airport activities (aircraft and/or handling and infrastructure). Those activities will dominate the pollution concentrations and significant concentration changes will likely be caused by these sources.
3	This station is located in a residential area that is located downwind of the airport, but without a dominant emission source in its proximity.	This station will give the average situation of a residential area with permanent housing closest to the airport and downwind from it. A source attribution might not be possible, but is not necessary.
4	This station is located next to a major traffic road, but still in the proximity of the airport.	Road traffic is an important emission source in general. This station reflects road traffic impacts on local air quality in the vicinity of the airport. There is no discrimination for airport related traffic versus any other traffic.
5	This station is located in another residential area, but downwind of an industrial area with emissions.	Residential areas could still be subject to increased concentrations. In this case it is important to discriminate emission sources that are not airport related but can impact areas close to the airport.
6	This station is located further away from the airport, but again in residential areas downwind of the airport.	It can be expected that further downwind from the airport, concentrations will decrease, provided no other significant emission sources are present.

5.3.3.4 In choosing the locations at and around the airport with regard to most likely dominant pollution contributors, it can be possible to estimate qualitatively the relevance of air traffic and airport induced impacts.

5.3.4 **Measurement Methods**

5.3.4.1 Various measurement methods are available that can range between simple (in terms of location site and handling) to sophisticated. The choice of each instrument must be made according to the expected measurement exigency. This exigency definition rests on the analysis of customer or authority demand when it is not compulsory by law. In any case, the risk of providing a wrong result when comparing to a threshold must be discussed and accepted by all "parties".

5.3.4.2 The main difference between measurement systems is whether they are active (system collects air samples and analyses continuously) or passive (ambient air is reacting with the system and results will be obtained remote). Table 5-2 discusses both systematic approaches for various parameters that need to be considered when evaluating measurement systems.

Table 5-2: **Active and Passive Measurement Systems**

Parameter	**Active System**	**Passive System**[12]
Possible Systems	Optical Path: • DOAS (differential optical absorption spectroscopy) Continuous Point • TEOM (Tapered Element Oscillating Microbalance) • Beta-Attenuation Mass Monitor • High Volume Samplers • Chemiluminescence	• Bag/Canister • Passive Diffusion Tubes • Filter papers
Pollution species to be measured	Usually multiple species can be measured in one station (e.g. NO_2, O_3, PM10) by using several analysers in one location.	Usually only one pollutant can be measured; some pollutants cannot be measured at all (reactivity).
Analysis	Air samples are usually analysed directly in the station and when sampled.	Samples are usually analysed remote in a laboratory and after collection.
Measurement Intervals	Depending on the equipment, the measurement intervals can be short, e.g. samples can be analysed every few seconds or minutes.	Intervals are usually long (e.g. two-week-intervals) or only one-time measurements.
Data Accuracy	The accuracy of the data obtained is usually fairly high, provided proper installation and maintenance of the systems.	The accuracy of the measured data is fair. However, for trend or comparison analysis with a larger number of sites, the accuracy may be sufficient.
Site requirements	The measurement site requires an unobstructed location (with regard to air flow), a sheltered room for the equipment and analysers and access to electrical power. Depending on the system, communication lines for remote operations are also needed. Some access restrictions should apply. Such a system can also be mobile for measurement campaigns.	The measurement site requires an unobstructed location (with regard to air flow). Only limited infrastructure is required to install the measurement system (no shelter, no power).
Maintenance	An increased level of maintenance on electrical / electronic and precision parts is required to obtain and maintain a reliable level of operability. This may include regular calibration or exchange of critical parts.	Maintenance efforts are usually low as no or only limited electrical / electronic or high precision parts are involved.
Costs	Medium to high (investments) and medium (maintenance).	Low (investments and maintenance).

[12] Bioindicators/bioaccumulators: This category is more a hybrid of an active system and long-term exposition. A limited description is given in the Annexe.

5.3.4.3 By considering potential sites in combination with measurement systems, it can be concluded that sites at the airport could be equipped with active and/or passive systems, while air quality measurements in the airport region are performed with passive systems.

5.3.5 **Management Planning**

5.3.5.1 An important element of ambient air quality measurement is assuring that implementation and actual execution is properly accounted for. To this end, several elements have to be addressed, defined and documented in the management planning. These include the following:

- Project Responsibility
- Maintenance
- Data Management
- Communication
- Quality Assurance and Quality Control

5.3.5.2 The project responsibility includes, but is not limited to the elements of drafting of the measurement concept, acquiring the necessary budget for acquisition, installation, operation and maintenance of the measurement equipment, organising the data management (evaluation, verification, storage) and managing potential third party contracts. It defines the roles and responsibilities of all involved parties.

5.3.5.3 Maintenance involves all of the elements of regular and preventative maintenance of the measurement equipment, as well as the repair and potential contingency planning by having spare equipment available. It also deals with the aspects of calibration of the equipment following manufacturer instructions or general guidelines and recommendations.

5.3.5.4 The data management comprises the data acquisition (automatically or manually), the data storage, and the data transfer (e.g. from remotely controlled stations). Once the raw data is obtained, it is subject to a quality check that needs to be predefined where inappropriate data is being identified and either marked or removed from the data series. Depending on the data acquisition system and required evaluation and reporting interval, the data might have to be aggregated into a different interval (e.g. hourly value).

5.3.5.5 Once the data is available for proper interpretation, there might be requirements for communication and /or publication. Public or restricted measurement reports may be produced and distributed by means of printed or electronic reports. In addition, communication to authorities or local stakeholder might be pre-defined.

5.3.5.6 In order to ensure long term quality of measured data, a quality assurance process is recommended where all elements influencing the quality of the data are addressed. Such a quality control system is developed and implemented to ensure that the required level of confidence in the system and its results are achieved.

5.4 Analysis of Data

5.4.1 Introduction

5.4.1.1 Ambient air measurement data can be used in a variety of ways, such as:

- Describing existing conditions in an area or a site, and demonstrating whether or not ambient air quality standards are being met
- Determining hourly, daily, monthly, and seasonal variation
- Determining trends
  - Spatial
  - Temporal
- Identifying major sources that contribute to measured concentrations

5.4.1.2 How the data can be used is dependent on the:

- specific pollutants or constituents that were measured
- duration (days, weeks, months, or years) of the measurements
- time resolution (seconds, minutes, hours, or longer) of the measurements
- number and location of monitoring sites used to collect the measurements
- meteorological data (e.g., wind speed and direction)

5.4.2 Describing Existing Conditions vs. Ambient Air Quality Standards

5.4.2.1 Ambient air quality monitoring is the traditional method for demonstrating that an area currently meets the applicable air quality standards. Often, monitoring must be conducted for one to three years prior to a formal designation and determination that an area attains or does not attain a standard. Regulatory agencies have defined how the data may be used in comparing the monitored results with the air quality standards.

5.4.2.2 Monitoring at one or more sites near an airport provides information regarding local air quality in the vicinity of the airport. This data may be used for defining the existing or baseline conditions in an environmental disclosure document for a proposed future project. Since air quality standards include the averaging period, and the averaging periods for certain standards are up to one year, monitoring must be conducted for the period appropriate to the standard in which the data will be compared. Longer monitoring may be required if the standard is based on a limited number of measurements that can be exceeded over a number of years.

5.4.3 Determining Periodic Variations

5.4.3.1 Periodic variations may give some clues as to which sources may be contributing to the measured concentrations. Each source at an airport has associated peaking characteristics. For example, regional surface traffic often follows a morning or evening work-related period peak. Aircraft operations often have distinct peaks. Ground vehicle access to an airport may peak 60-90-minutes before and after the peak aircraft operations. If hourly monitored data are available, and these data show pollutant concentration peaks corresponding in time with the rush hour periods, then traffic is likely a major contributor to the measured values. Note that this assumes one is looking at a relatively inert pollutant (such as CO, PM10, or total NOx).

5.4.3.2 The variation may also be by day-of-week, month-of-year, or seasonal. These variations may also help point to the sources or source types that may be substantial contributors to the measured concentrations. However, one should note the periodic variations may also be associated with meteorological effects, such as temperature, mixing height, or relative humidity that actually change either the pollutant emissions from sources. For example, combustion sources produce more NOx and less CO when the ambient air temperature is higher producing both diurnal hourly fluctuations and seasonal variations.

5.4.3.3 A typical example of a source dependent variation is the pollution concentration of aircraft. There might be airports with distinct seasonal traffic (e.g. winter sports destination) of even weekend traffic. A typical example of a variation that corresponds with meteorological conditions might that of an airport power plant that operates at fairly regular load conditions throughout the year.

5.4.4 **Trend Analyses**

5.4.4.1 Spatial gradient analysis uses ambient air measurements of a single pollutant made at multiple locations to identify and locate emission sources that contribute to the measurements.

5.4.4.2 Time series analysis uses ambient air measurements of a single pollutant made at multiple locations to identify patterns of pollutant concentrations over time.

5.4.4.3 Long-term (multiple years) data collection at one location can provide information on the general trends in pollution emission. In many areas where on-going pollution control programs have been in place, the long-term trend show steady reductions in measured pollutant concentrations over time.

5.4.5 **Source Apportionment**

5.4.5.1 Source apportionment is the use of monitored or modeled concentrations, with or without meteorological data, to determine the sources, source types, and/or source locations that contribute substantially to measured values. The spatial gradient and time series analyses discussed above are possible source apportionment methods. Others include the chemical mass balance or the positive matrix factorization.

5.4.5.2 The use of monitored data to determine sources that contribute to the measurements is referred to as receptor modeling. The receptor (monitoring station) data is analyzed along with either wind speed and wind direction data or assumed source type emission profiles and characteristics to tease out information about which sources or source types are generating the emissions that get measured at the station.

5.4.5.3 Measurements at a point do not allow one to distinguish from different contributing sources unless a tracer substance can be isolated that is emitted from a specific source only. Therefore, it is important to conduct modeling in conjunction with measurements in order to estimate the contribution from individual sources or groups of sources (e.g., an airport).

5.4.6 **Handling of Missing Data**

5.4.6.1 Local or national guidelines usually set forth the required conditions under which measured time series are valid. For longer-term measurements (e.g. annual), a maximum number of days without data is allowed where no specific action has to be taken. Gaps beyond this tolerance will lead to invalid measurement series or averaging periods. The obtained data can be used for information purposes, but may not be used for legal reporting or justification for mitigation programs. Where such guidelines allow, missing data can be inserted by ways of interpolation. In all cases, data gaps should clearly be documented.

5.4.6.2 Interpolation of one or several missing data points can be done by consulting a valid measurement period from a nearby station with comparable meteorological conditions and to use the variation in the measurement points in a corresponding manner. In any case, any interpolated data has to be marked as such.

5.5 Measurement Quality Assurance/Quality Control

5.5.1 Quality Management Guidelines

5.5.1.1 One of the main targets in quality management is to provide confidence that the measurements are accurate to avoid criticism when communicating the results. The quality management process will help to minimize uncertainty by optimizing equipments performance as well as the technician capabilities. Furthermore, the monitoring results must be readily available; it must be traceable, well identified, documented and unique in time and location.

5.5.1.2 There may be a number of guidelines available. This could include, but is not limited to manufacturer specification, local or national guidelines or international guidelines (International Standards Organization). ISO 9001: the reference for quality management, deals with the processes for organizing the measurement information that allows for customer satisfaction. ISO 17025: based on the same quality management organization and goal as the ISO 9001 standard, and specially built for measurement activities, adds the technical capability evaluation and is much more constraining than ISO 9001.

5.5.2 Technical Competence

5.5.2.1 An important factor in assuring the quality of measurements is the skill and expertise of staff performing the measurements. As such, adequate technical skills need to be achieved for all elements of air quality monitoring: equipment installation, operation, maintenance and repairs and data handling: obtaining, storing, validating and interpreting. The minimum educational level should be defined in advance and documented.

5.5.2.2 In order to assure the required level of expertise, a training schedule can be developed that includes internal and external training e.g. by the equipment manufacturer or environmental authorities. This is particularly true for complex analysis instruments with frequently changing technologies. It is recommended to document all training programs (e.g. according to ISO 9001). Training programs have to be on a repetitive basis.

5.5.3 Equipment Accuracy

5.5.3.1 The necessary (preventative) maintenance procedures including the periodicity have to be prescribed by the equipment manufacturer. Preventive maintenance must be programmed regularly for the equipment to assure optimum performance during operation, particularly during continuous monitoring and communication of the data. Preventative maintenance could include cleaning, change of specific equipment parts, software updates and others. All maintenance activities must be scheduled and documented, as well as the findings after each performed maintenance.

5.5.3.2 Calibration of the equipment is an important, necessary step, and is done to assure that the measurements are accurate and within the given range of the equipment. Calibration is done after regular, pre-defined intervals after each preventative maintenance and repair. When additional calibration equipment or substances (e.g. reference gases) are used, they must be quality assured or certified (e.g. expiration date on reference gases). Controlled temperature and humidity may be necessary for specific calibrations and they have to be respected. All information pertaining to the calibration of the equipment has to be logged.

5.5.3.3 Despite all maintenance and calibrations, some uncertainty might remain. It is important to understand the magnitude of such uncertainty and the level of impact it has on the overall measured values in order to determine the degree of fidelity of the final data. An uncertainty study could help determine the various factors and their relevance for ambient measurements and could also suggest ways to minimize the uncertainty of the data.

5.5.4 **Data handling**

5.5.4.1 Depending on the way of monitoring, a large volume of raw data may be compiled over time that requires specific data management. It has to be decided whether both raw and validated/processed data need to be kept and over what period of time. A suggested way forward would be to keep the raw data for a period of at least 10 years, while the processed data (validate, aggregated, etc) could be kept for more than 10 years.

5.5.4.2 Data storage will require a maintenance process, such as regularly recopying the data from one medium to another and at the same time crosschecking for data faults (missing, falsified). This data management process has to be documented as well.

5.5.5 **Accreditation and Certification**

5.5.5.1 Periodical checks must be done to be sure that the management procedures are conveniently applied. Internal auditors could be recruited among the employees and trained for this activity.

5.5.5.2 Even if external companies have an established and maintained quality system, the customer (e.g. the airport) would have to have the confidence in such a system. To this end, the current minimum standard is an ISO 9001 certification label. In addition, the ISO 17025 standard is specifically adapted to the measurement activity and, as it combines quality management based on ISO 9001 guidelines with a clear focus on the technicians' capability, it is the best way to ensure the customers' confidence.

Annexe 5A1 Description of Selected Measurement Methods

<u>**A. Active Systems**</u>

1. **Differential Optical Absorption Spectroscopy (DOAS)**

With the DOAS-system it is possible to obtain automatic measurements along a path with high resolution. The principle is based on the wavelength dependent absorption of light caused by gases. The DOAS-equipment includes an emitter and a receiver unit. A light beam with a wavelength between 200 and 700 nm is projected from the emitter to the receiver and passes to an analyzer through a fiber optic cable. In the path, specific gases will absorb light from known parts of the spectrum. This allows the analyzer's computer to measure gases through a spectrometer. Within the spectrometer a grater set splits the light stepwise into the different spectra. The resulting spectrum is now compared with a reference spectrum and the difference calculated to a polynomial. With additional calculations the differential absorption spectrum and finally the concentration of the particular gas is determined. These single measurements are summarized to 30 minutes values. This system can be used for a range of pollutants including nitrogen dioxide, ozone and sulphur dioxide.

2. **Tapered Element Oscillating Microbalance (TEOM)**
The TEOM (Tapered Element Oscillating Microbalance) allows one to determine the PM_{10}-fraction of dust. The TEOM-method is based on the principle that the frequency of an oscillating filter changes with increasing mass. The TEOM takes air samples of known volume, which passes through a filter on the top of the sampling unit. Here all particulate matter with a particle-size lager than 10 µm is separated. The air sampling then passes through a second filter on which the particles smaller than 10 µm drop behind. The concentration of PM_{10} is calculated from the changes of the frequency of the filter-oscillation. The single measurements are summarized to 30 minutes values.

2a. **Beta-Attenuation Mass Monitor (BAM)**
The BAM is a more rugged and less expensive continuous monitor for PM_{10} and for $PM_{2.5}$ than the TEOM. It has USEPA certification (EFQM-0798-122) as an Equivalent Method to the standard method for monitoring ambient air PM_{10} and $PM_{2.5}$. The BAM method uses a stable radio-active carbon source (^{14}C, 60 uCi), and it measures attenuation of Beta radiation by particulate matter deposited on a filter medium and relates the attenuation to the mass deposited on the filter. PM_{10} or $PM_{2.5}$ levels are measured separately, depending on the particle size discriminator placed before the filter collection device.

3. **NO_X-Analyzer**
The NO_X-analyzer is used to measure the NO_2-concentration. The analyzer takes two air samples. One stream passes through and the other stream passes through a convertor that reduces NO_2 to NO. Both samples are analyzed for NO in a single reaction cell, where the chemiluminescence produced by the reaction between NO and O_3 is measured. The instrument alternately measures the total NOx and NO. The difference between the two readings results in a computed NO2 value in the ambient air.

4. **O_3-Analyser**
In the O_3-analyser, two air samples are collected. The first one passes through a catalyst which converts O_3 to O_2. The second sample goes directly into an absorption cell (reference measurement). A detector measures the amount of ultraviolet (UV) radiation transmitted. The O_3 concentration is calculated from the two reference values. The interval of measurement is 30 minutes.

Conclusions

Automated analyzers allow for the continuous, automated, on-line and time-resolved measurement of air pollutants, producing high-resolution measurements of hourly pollutant concentrations or better, at a single point. The major drawback of a continuous point/optical path method, such as the DOAS method, is the high cost associated with purchase and maintenance of the analyzers. Consequently, low network density and low spatial resolution of the measurements may result. Mobile laboratories equipped with automated analyzers constitute a useful application of this technique as a tool for measurement programs covering several locations of interest.

B. Passive Systems

1. Diffusion Tubes

Diffusion tubes are the simplest and cheapest way to evaluate local air quality of gaseous pollutants and can be used to give a general indication of average pollution concentrations over longer time periods ranging from a week or more. They are most commonly used for *nitrogen dioxide* and *benzene* (often with *toluene*, *ethyl-benzene*, *m+p-xylene* and *o-xylene* as BTEX), but are also useful for measuring a number of other pollutants such as *1,3 butadiene*, *ozone*, *sulphur dioxide*, etc.

Diffusion tubes generally consist of a small tube (test-tube size) normally made of stainless steel, glass orinert plastic, one end containing a pad of absorbent material and the other end is opened for a set exposure time. After exposure, the tubes are sealed and then sent to a laboratory where they are analysed using a variety of techniques including chemical, spectrographic and chromatographic processes.

It should be noted that diffusion tubes are an *indicative* monitoring technique that do not offer the same accuracy as the more sophisticated automatic analysers. Also, since the exposure periods can be several weeks, the results cannot be compared with air quality standards and objectives based on shorter averaging periods such as hourly standards - it is not possible to detect peak events using diffusion tubes for the same reason. As a result, although diffusion tubes can be used for shorter period assessments, it is recommended that NO_2 diffusion tube monitoring, in particular, be carried out over a full year as assessments against objectives for annual mean concentrations can then be made.

Diffusion tubes can be affected by a number of parameters that may cause them to over-read, or under-read, relative to a reference measurement, and for this reason, best practise is to use three or more tubes at each monitoring point, and co-locating one set with an existing reference continuous monitor. This way any bias can be corrected by referring the results back to the continuous monitor (e.g. chemi-luminescant monitor for NO_2), and comparison between the tubes will identify any anomaly.

It is important to choose sites for diffusion tube monitoring correctly, and the area around the tube location should allow for the free circulation of air around the tubes, while avoiding areas of higher than usual turbulence such as corners of buildings etc. Care should also be taken to avoid surfaces that may act as local absorbers for the pollutant being measured, and for this reason diffusion tubes should not be fixed directly on walls or other flat surfaces. Other localised sources or sinks such as heater flues, air conditioning outlets, extractor vents, etc as well as trees and other areas of heavy vegetation, should also be avoided.

The relatively low cost of diffusion tubes means that sampling is feasible at a significant number of points over a large area, and this can be useful for identifying relative trends, and also regions of high concentrations where more detailed studies can then be carried out. Under these circumstances, the cost and difficulty of using more accurate continuous monitoring to carry out the same study would almost certainly prove prohibitive.

2. **Bags/Canisters**

For this measurement technique, a "whole air" sample is collected at selected measurement sites by drawing an ambient air sample into some sort of container. Most commonly, this could be a bag, glass bulb, steel "bomb" or a stainless steel canister. Stainless steel canisters and bags are the most common collection systems. The collection of an air sample may be enhanced with a small electric pump that actively fills the canister with the ambient air sample.

Once the gas is collected in the canister, it is analyzed off-site by several different methods (e.g. using solution chemistry). Measured ambient air components are often various hydrocarbon species.

Data quality issues usually revolve around the recovery of contaminants from the collection vessel. Recovery is a function of several parameters including, the chemical nature of the contaminant and the surface properties of the vessel, the vapor pressure of the contaminant, the influence of various other compounds contained in the matrix, and the ability to start with a vessel free of contamination.

Conclusions
Passive sampling methods are simple and cost-effective methods which provide a reliable air quality analysis giving a good indication of average pollution concentrations over a period of weeks or months. Other methods include the use of bubblers for gaseous pollutants and the analysis of heavy metals contained in the suspended particulate matter filtrate.

C. Other Methods

1. **Bioindicators**
Biological indicators, or bioindicators, are plant or animal species which provide information on ecological changes in site-specific conditions based on their sensitive reactions to environmental effects. Bioindicators can provide signs of impending environmental problems such as air and water pollution, soil contamination, climate change or habitat fragmentation. They can also provide information on the integrated effect of a variety of environmental stresses and their accumulative effects on the health of an organism, population, community and/or ecosystem. Lichen species are a commonly-used bioindicator for air quality.

Various methods of investigating indicator species exist, and at the individual organism level the effects of bioaccumulation can be studied. At the population level, studies of morpho-physiological changes, changes in life cycles, relative health of populations, and population and community structures can all be conducted. Marking and recapturing, establishing sex and age ratios, point, line, plot or plotless surveys of vegetation cover and plant frequencies, etc. are examples of the ecological field methods which are used.

The data obtained from traditional measurements methods permit control of compliance with current air quality standards and limit values. Data on ambient pollutant concentrations, however, do not allow for direct conclusions to be drawn on potential impacts on humans and the environment. Evidence of harmful effects can more accurately be provided through use of bioindicators. Bioindicators also integrate the effects of all environmental factors including interactions with other pollutants or climatic conditions. This permits the risk of complex pollutant mixtures and chronic effects that can even occur below threshold values.

The use of bioindicator plants to assess air pollution effects is not very well established. Insufficient standardization of the techniques and, consequently, the low comparability of the results is one of the major reasons for the poor acceptance of this air quality monitoring methodology.

Annexe 5A2 Examples of Measurement Methods

Table 5-A2: Example table of measurement methods (from Europe and US)

Pollutant	**Reference Method**	**Other Methods**
Sulfur Dioxide	Ultraviolet Fluorescence	DOAS
Nitrogen Dioxide and Oxides of Nitrogen	Chemiluminescence	DOAS
PM_{10}	Gravimetric	TEOM (Advanced) Beta Attenuation Sticky Tape (Simple)
$PM_{2.5}$	Gravimetric	
Lead	Gravimetric	
Carbon Monoxide	Gas Filter Correlation Non-Dispersive Infrared Spectroscopy (EU)	
Ozone	Ultraviolet Photometry	DOAS

Annexe 5A3 References (selection)

Aeroport De Paris – Charles De Gaulle, 2006. "Campagne De Prelevement De Dioxyde D'azote Par Tubes Passifs"

Carslaw, D.C., S.D. Beevers, K. Ropkins, and M.C. Bell, 2006. "Detecting and quantifying aircraft and other on-airport contributions to ambient nitrogen oxides in the vicinity of a large international airport," *Atmospheric Environment* 40:5424–5434.

Chow, J.C., L.W.A. Chen, J.G. Watson, D.H. Lowenthal, K.A. Magliano, K. Turkiewicz, and D.E. Lehrman, 2006. "PM2.5 chemical composition and spatiotemporal variability during the California Regional PM10/PM2.5 Air Quality Study (CRPAQS)," *Journal of Geophysical Research*, Vol. 111, D10S04, 17 pages.

EPA's ambient air quality measurements guidance, http://www.epa.gov/ttn/amtic/cpreldoc.html

FAA, Air Quality Procedures For Civilian Airports & Air Force Bases, April 1997, and 2004 Addendum, http://www.faa.gov/regulations_policies/policy_guidance/envir_policy/airquality_handbook/media/Handbook.PDF

Fanning, E., R.C. Yu, R. Lu, and J. Froines, 2007. "Monitoring and Modeling of Ultrafine Particles and Black Carbon at the Los Angeles International Airport, Final Report," ARB Contract No. 04-325, prepared for the California Air Resources Board and the California Environmental Protection Agency, Sacramento, CA (June 20).

Henry, R.C., 2002. "Receptor Modeling," *Encyclopedia of Environmetrics*, A.H. El-Shaarawi and W.W. Piegorsch, Editors, John Wiley & Sons, Ltd, Chichester.

Henry, R.C., Y.-S. Chang, and C.H. Speigelman, 2002. "Locating nearby sources of air pollution by nonparametric regression of atmospheric concentrations on wind direction," *Atmospheric Environment* 36:2237–2244.

Henry, R.C., 2008. "Locating and quantifying the impact of local sources of air pollution," *Atmospheric Environment* 42:358–363.

RWDI, 2003. "Air Quality Study: Phase 4 - Ambient Air Quality Monitoring," Toronto Pearson International Airport, Toronto, Ontario, Canada (November 12).

Unique (Flughafen Zürich AG), 2007: "Air Pollution Monitoring," Concept and Description (www.unique.ch),

Watson, J.G., J.C. Chow, J.L. Bowen, D.H. Lowenthal, S. Hering, P. Ouchida, and W. Oslund, 2000. "Air Quality Measurements from the Fresno Supersite," *J. Air & Waste Manage. Assoc.* 50:1321-1334.

Yu, K.N., Y.P. Cheung, T. Cheung, Ronald C. Henry, 2004. "Identifying the impact of large urban airports on local air quality by nonparametric regression," *Atmospheric Environment* 38:4501–4507.

www.heathrowairwatch.org.uk

— — — — — — — —

Revised text for the Guidance Manual
Road Vehicle Inventory Chapter

A4.3.4 For airport-related vehicles, emission factors are available from the following sources:

- U.S. EPA MOBILE6.
- California's EMFAC2002.
- CITEPA method based on COPERT-IV.
- EUROCONTROL ALAQS method based on COPERT-IV.

A4.4 Model Variations of Pollutant Emission Factors

A4.4.1 The vehicle emissions models cited in A4.3.4 are provided as sources of current and future road vehicle emission factors, but were originally designed for the purpose of monitoring the effect of national and/or local air quality legislation [MOBILE6, CITEPA]. These models estimate a number of exhaust pollutants including CO, HC, NO_x, PM, SO_x, select HAP and carbon dioxide CO_2. Evaporative emissions from fuel and PM emissions from brake- and tire-wear are also provided in many cases.

A4.4.2 The pollutants relevant to road vehicle emissions are divided in legislated and non-legislated groups. The pollutant species that are typically modelled are shown in the following tables. When selecting a model it is important to note that some vehicle emissions models will report pollutants differently, e.g. some might provide a breakdown of Hydrocarbons and volatile pollutants, whilst others might aggregate these as one pollutant. Among other pollutants that are not included, lead may need to be calculated if leaded fuel is still in use and if a leaded fuel emissions factor is available.

Base pollutant Set – Legislated

The listed in the table indicate the pollutants subject to air quality legislation in one more nations.

Pollutant	Remarks
CO	
HC	Some models may provide results per component pollutant – see extended set of pollutants below
NO_x (NO_2 + NO)	Some models may report NO_2 and NO separately.
SO_x	
PM_{10}	
$PM_{2.5}$	May be included in the report for PM_{10}

Extended Set – non-legislated

Some models are able to report an extended set of pollutants if the appropriate indices are available.

Pollutant	**Remarks**
1.3 Butadiene	
Acetaldehyde	
Acrolein	
Benzene	
CO_2	Most models will calculate fuel burn, hence CO_2 can be derived. But as CO_2 is not a LAQ gas we include it in the extended set.
CH_4	
Cu	
CHCO	
HCB	Maybe included in HC
N_2O	
NH_3	
MTBE	
PAH : BaP, BbF, BkF, IndPy	Maybe included in HC
PCDD-F	Maybe included in HC
TSP	

— — — — — — — —

APPENDIX D

Report on the Use of Environmental Management Systems (EMS) in the Aviation Sector

International Civil Aviation Organization (ICAO)
Committee on Aviation Environmental Protection (CAEP)
February 2010

Table of Contents

Executive Summary

Pressure on the aviation industry to balance increasing demand with environmental protection is at an all time high. Therefore, an effective approach to sustain operations and meet future environmental requirements is critical. The International Civil Aviation Organization's (ICAO) Committee on Aviation Environmental Protection (CAEP) is the international forum of expertise for the study and development of proposals to minimize the impact of aviation on the environment.

At the seventh Meeting of CAEP (CAEP/7) in February 2007, the Land Use Planning and Noise Management Task Group (TG) was asked to deliver a report at the Eighth Meeting of CAEP in February 2010 providing information on the use of environmental management systems (EMS) and, as appropriate, make recommendations on how the committee could promote the use of EMS within the aviation system. In response, the TG developed an industry questionnaire to learn more about the application and potential value of EMS to aviation organizations. The questionnaire and accompanying introductory state letter were distributed worldwide by member states and industry associations in May 2008. Approximately 326 organizations responded to the questionnaire; these organizations were categorized into five different sectors, including air navigation service providers (ANSPs), airlines, airports, manufacturers, and other aviation organizations. After validating the questionnaire data, information from 233 responses formed the basis of this report to CAEP/8 and supported the development of recommendations.

Approximately 50 percent of questionnaire respondents (a total of 117) apply EMS standards or guidelines, with the majority having an ISO-14001 v2004 certified EMS in place. The remaining 116 respondents that have other environmental programs in place have many of the same principles and practices that are required as part of a formal EMS. For those organizations with an EMS, 82 percent have additional management systems in place—approximately 51 percent of these additional systems are integrated or coordinated with the organization's EMS. Over the past ten years, EMS implementation has been relatively consistent in the aviation industry. On average, respondents indicated that 6-12 months are needed to successfully develop and implement an EMS. Approximately 71 percent of organizations had assistance with EMS implementation from a consulting or contracting firm.

Regardless of whether the respondent organization had an EMS in place, measuring environmental performance is important for ensuring compliance. On average, the majority of questionnaire respondents communicate environmental performance through a corporate social responsibility report or through their organization's website. Environmental areas of regulatory concern were a primary focus of organizations regardless of whether they implemented an EMS or not. 79 respondent organizations without an EMS plan to implement one in the future. These organizations indicated that the most common reason for not implementing an EMS was unfamiliarity with EMS approaches. As a result, aviation industry specific EMS implementation guidance was requested by these organizations.

The information provided by respondents forms the basis of two recommendations. These focus on increasing awareness of EMS principles and best practices in the aviation sector and establishing practical guidance to assist those organizations that choose to use EMS to enhance the way they manage environmental issues. Awareness and guidance materials should integrate existing ICAO environmental tools, guidelines, and manuals. Where possible they should encourage organizations to support higher-level ICAO environmental objectives, consider the collaborative nature of the aviation industry, and account for variance in operation type (i.e., sector type) and the level of EMS maturity at the organization.

Recommendations

Disseminate Report Information. Within the first year of the CAEP/9 cycle, ICAO should make the information contained in this report publicly available. A report should be distributed specifically to those organizations who responded to the questionnaire and more broadly, via member states, to the aviation sectors in their state.

Develop EMS Guidance. Stand alone EMS guidance should be developed for the end of the CAEP/9 cycle. This should assist organizations to determine how EMS elements and principles can be used to enhance the way they manage environmental issues and provide practical guidance on how these EMS elements and principles can be implemented/integrated into existing management systems and business processes.

Main Report

Chapter 1. Introduction

1.1. Background

Global demand for air travel is estimated to increase significantly in the future. While the benefits of this growth will be substantial, it is likely to be accompanied by an increase in aviation-related environmental impacts. Local air quality, ambient noise levels, water quality, energy use, and climate change are some of the most prominent impacts of concern. Pressure on the aviation industry to balance increasing demand with environmental protection is at an all time high. Therefore, an effective approach to sustain operations and meet future environmental requirements is critical. Identifying the significant environmental impacts of aviation, and effectively managing these impacts efficiently through the use of technology, procedures, and policy is likely to play an important role in the sustainable growth of the aviation industry.

1.1.1. ICAO and the Environment

The International Civil Aviation Organization (ICAO) is a specialized agency of the United Nations created in 1944 to promote the safe and orderly development of global air transport. ICAO's work on the environment focuses primarily on those problems that benefit most from a common and coordinated approach on a worldwide basis, namely aircraft noise and engine emissions. The following environmental goals have been established by ICAO:

- limit or reduce the number of people affected by significant aircraft noise;
- limit or reduce the adverse impact of aviation emissions on local air quality; and
- limit or reduce the impact of aviation greenhouse gas emissions on the global climate.

ICAO's Committee on Aviation Environmental Protection (CAEP) is the international forum of expertise for the study and development of proposals to minimize the impact of aviation on the environment. Membership consists of experts from members and observers from states, including intergovernmental and non-governmental organizations representing aviation industry and environmental interests. CAEP is responsible for conducting studies and recommending measures to minimize and reduce aviation's impact on the environment, and for maintaining certification standards for aircraft noise and aircraft engine emissions. Recommendations made by CAEP are reviewed and adopted by the ICAO Council. The Council reports to the ICAO Assembly where the main policies on aviation environmental protection are defined and translated into Assembly Resolutions.

Since its creation in 1983, the role of CAEP has progressively expanded from one of basic standards setting, to the development of broad policy measures such as the balanced approach to limit or reduce the impact of aircraft noise, and the creation of market-based measures to handle noise and emissions charges and emissions trading. In order to achieve a greater understanding of the environmental impacts of aviation, CAEP encourages research through the collection, generation, analysis, harmonization, exchange, and dissemination of information related to aviation environmental issues. CAEP's work often results in published reports, guidance material, and/or specific studies.

1.1.2. CAEP/8 EMS Task

Environmental management systems (EMS) provide a methodology and framework to systemically identify and cost-effectively manage significant environmental aspects of aviation organizations' operations. They have proven effective across a wide range of organizations, including airports, air carriers, manufacturers, and government agencies. As a result, international recognition of the potential value of EMS as a tool to help aviation organizations manage their environmental issues is increasing. ICAO would like to further understand the application of EMS by aviation organizations, encourage implementation where this may help organizations overcome environmental challenges, and better use environmental opportunities.

At the Seventh Meeting of CAEP (CAEP/7) in February 2007, the Land Use Planning and Noise Management Task Group (TG) was asked to deliver a report at the Eight Meeting of CAEP in February 2010 providing information on the use of environmental management systems (EMS) and, as appropriate, make recommendations on how the committee could promote the use of EMS within the aviation system. In response, the TG formed an ad hoc group to perform the task and proposed a questionnaire to gather information for the report. The US Federal Aviation Administration agreed to lead the effort and an ad hoc group was formed with representatives from Transport Canada, Italy, International Coordinating Council of Aerospace Industries Associations, International Air Transport Association, and Airports Council International.

The TG developed an industry questionnaire to learn more about the application and potential value of EMS to aviation organizations. The questionnaire and accompanying introductory state letter were approved by the ICAO Secretary General on 16 May 2008. The questionnaire and letter were distributed worldwide by member states and industry associations. Approximately 326 organizations responded to the questionnaire over a period of six months. After validating the questionnaire data, information from 233 responses formed the basis of the report to CAEP/8 and supported the development of recommendations.

1.1.3. Objectives

The CAEP/8 task was to:

- *"deliver a report providing information on the use of EMS among airports, airlines and air navigation providers in order to give a base of understanding in the aviation sector;"* and
- *"based on the report, as appropriate, make recommendations on how the committee could promote the use of EMS with in the aviation sector."*

1.2. Methodology

TG1 developed an industry questionnaire based widely on input from members of the working group to gain an understanding of environmental management practices in the aviation sector. This questionnaire was divided into eight sections that seek to understand the responding organization and their environmental management practices by inquiring about the following:

- environmental management drivers;
- approach to environmental management;
- performance monitoring and communication methods;
- resources required for implementation and maintenance; and
- lessons learned.

After several revisions by the TG, the questionnaire was finalized and an electronic version of the survey was developed so respondents could submit their responses online. On 16 May 2008, the questionnaire was distributed by states and industry associations with an accompanying introductory letter signed by the ICAO Secretary General.

Over a six month time period, responses were received via mail, fax, email, or through the questionnaire software program. All questionnaire responses were input into the questionnaire software program, either manually or directly depending on the method of submission. Once all responses were input into the questionnaire software program, the response data was validated based on the resolutions that were agreed on by the TG (Section 1.3. outlines the validation process that was used).

Following validation, individual sector data was forwarded to the appropriate industry association so a summary analysis could be conducted to characterize the respondents in a given sector. After the response data was validated and characterized by the appropriate industry association, the remaining response data was analyzed and formed the basis of the report to CAEP/8.

1.3. Questionnaire Data

As a result of the number and range of organizations from different countries that responded to the questionnaire, variation in the data exists. Common inconsistencies found among questionnaire responses included the submission of partially completed surveys; receiving multiple, different responses from the same organization; and having questionnaires with response data for both question sets, those for organizations with EMS and those for organizations without EMS. It was critical that data be as consistent as possible for strong informative analysis. Therefore, the TG developed resolutions for how common inconsistencies should be addressed prior to analysis. The resolutions agreed on by TG were as follows:

1. Delete those responses from the data set that provide no information on the organization's environmental management practices.

2. Delete those responses from the data set that are exact duplicates.

3. Request clarification from industry group or respondents for those responses that are from the same organization, but not exact duplicates.

4. Review data specifically by sector to see what can be done about inconsistent financial figures.

5. Request clarification from industry group or respondents for those responses that claimed they do not apply EMS standards/guidelines, but completed both sets of questionnaires for organizations with EMS and without EMS.

6. Delete the completed question set for organizations without an EMS for those organizations that claim to have an EMS and completed the question set for organizations with an EMS.

7. Change the organization's response to the question regarding whether or not they have an EMS to reflect the question set that they answered.

8. Delete those responses from the data set that do not provide sufficient information on the organization to validate that the response is accurate.

Of the 326 responses received, approximately 93 were not considered for analysis as a result of the agreed upon resolutions. The remaining 233 responses form the basis of the report to CAEP/8 and support the development of recommendations.

In addition to variation in the data, it should also be noted that the questionnaire respondents do not make up a random sample. The questionnaire and accompanying introductory letter that was distributed to industry associations and states encouraged the participation of all organizations in the aviation sector. However, since questionnaire participation was voluntary, those organizations who responded to the survey were more likely to have an environmental program in place. As a result, the sample of respondents is not representative of the aviation industry as a whole.

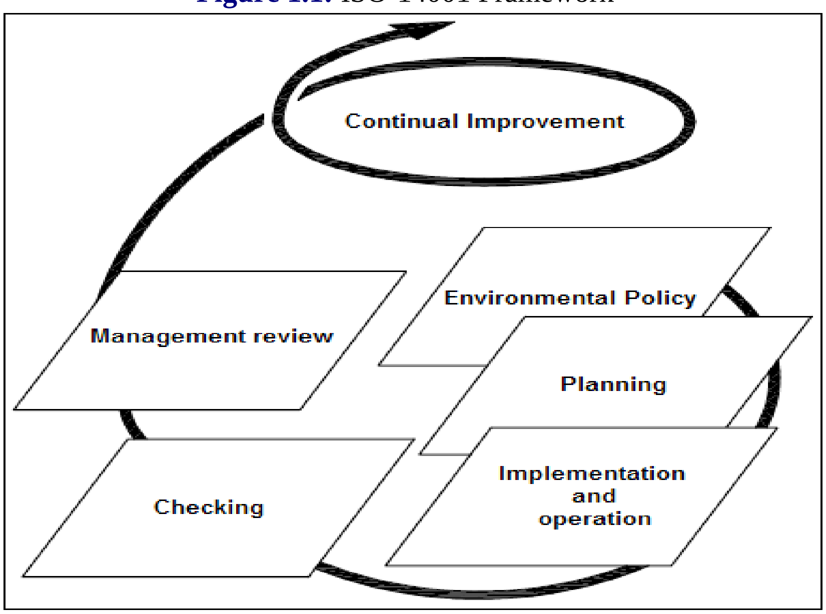
1.4. Introduction to EMS

As one of the most environmentally friendly forms of transportation, aviation organizations are increasingly using EMS among other approaches to meet their environmental challenges. A formal definition of EMS, developed by Transport Canada, is as follows:

"A systematic approach for organizations to bring environmental considerations into decision-making and day-to-day operations. It also establishes a system for tracking, evaluating and communicating environmental performance. An EMS helps ensure that major environmental risks and liabilities are identified, minimized and managed."

Formal Environmental Management Systems (EMS) emerged in the early 1990s to provide organizations with a proactive, systematic approach for managing the potential environmental consequences of their operations. Such systems have been widely adopted by industry and Government and have been effective at improving an organization's regulatory compliance and environmental performance. Although several recognized EMS frameworks exist, most are based on the International Organization for Standardization's ISO-14001 EMS standard, described by Figure 1.1.

Figure 1.1: ISO-14001 Framework



Environmental Policy
The organization establishes an environmental policy which provides an overaching vision and framework for environmental management at the organization.

Planning
The organization identifies how its operations might harm the environment, and develops objectives, targets, and programs to reduce this harm.

Implementation and Operation
The organization implements the systemic measures to control operations and reduce environmental impacts across all levels and functions of its operations.

Checking
The organization assesses its environmental performance and the effectiveness of its management system elements.

Management Review
Based on its assessment of the implemented systemic measures, the organization undertakes actions to make system adjustments and to promote continual improvement.

The EMS continually moves through this cycle, fine-tuning the management of those operations that harm the environment. This "continual improvement cycle" is a fundamental characteristic of the EMS; it allows the system to adapt to the dynamic nature of the organization's operations and external conditions.

Chapter 2. Questionnaire Participation

2.1. Introduction

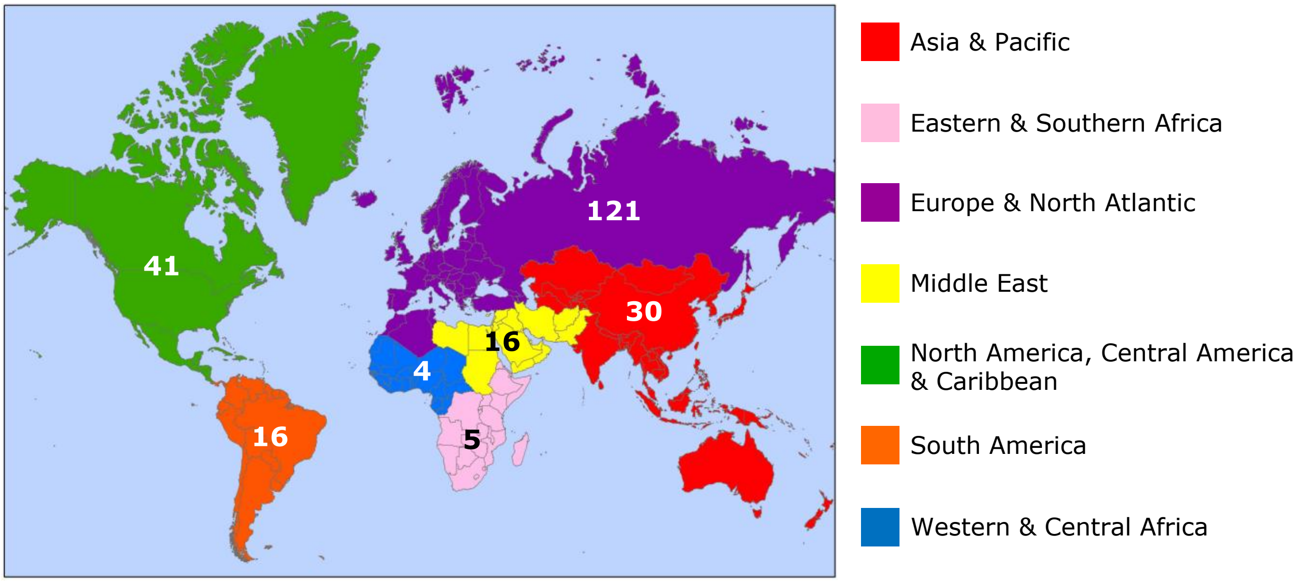
With the assistance of CAEP member states, observer organizations, and industry associations, questionnaires were disseminated worldwide to a wide range of stakeholders within the aviation industry. A total of 326 responses were received over a six month time period. Following validation, 233 of these responses were analyzed to form the basis of this report. This chapter will discuss and analyze the breakdown of these 233 responses by industry sector and geographic location.

Figure 2.1: *Number of valid survey respondents within each aviation industry sector.*

Sector Characterization	
Airlines	80
Air Navigation Service Providers	24
Airports	96
Manufacturers	10
Other	44
TOTAL	**254**

Note: CAEP received a total of 233 unique survey responses. When selecting a sector, respondents were able to choose multiple options.

Figure 2.2: *Number of CAEP survey respondents within each ICAO region.*



2.2. Sector Characterization

Individual sector response data was forwarded to the appropriate industry association for completion of a summary analysis that characterized the respondents in a given sector. These analyses contain statistical data specific to the questionnaire respondents and offer some insight on how representative these respondents are of the industry as a whole. In addition, each analysis provides an illustration of the geographic location of questionnaire respondents by sector.

2.2.1. Airlines

A total of 80 questionnaire respondents out of 233 were from passenger, cargo, or passenger and cargo airlines. These 'Airline' respondents transported an estimated 1.1 billion passengers and 55 billion ton kilometers of cargo in 2008. This represents approximately 67% of total system-wide scheduled passengers and 33% of total system-wide scheduled cargo carried by IATA member airlines in that year. Of the 80 airline respondents, 57 (or 71%) were IATA members.

2.2.2. Air Navigation Service Providers

A total of 24 questionnaire respondents out of 233 were from air navigation and air traffic service providers. Of the 24 'Air Navigation Service Provider (ANSP)' respondents, 18 are members of the Civil Air Navigation Services Organization (CANSO). Together, the CANSO member respondents move an estimated 57,370,000 aircraft per year.

2.2.3. Airports

A total of 96 questionnaire respondents out of 233 were from airport companies, airport authorities, and government and city departments that operate one or more airports. These 'Airport" respondents operate a total of 231 airports that have an estimated annual passenger throughput of approximately 1.15 billion.

The 96 'Airport' respondents represent approximately 17 percent of Airport Council International's (ACI's) 597 member organizations, and 5.7 percent of the 1,680 airports in ACI. In terms of passenger numbers, the 96 responses cover almost a quarter of the 4.8 billion passengers handled at ACI member airports annually.

2.2.4. Manufacturers

A total of 10 questionnaire respondents out of 233 are from aircraft and engine manufacturers. These 'Manufacturer' respondents represent approximately 50 percent of the International Coordinating Council of Aerospace Industries Association (ICCAIA) membership.

2.2.5. Other

A total of 44 questionnaire respondents out of 233 were from a variety of 'Other' organizations including fixed base operations, corporate aviation flight departments, aviation academies and flight schools, and aircraft and engine maintenance organizations. When completing the questionnaire, respondents were able to identify themselves as belonging to multiple sectors. As a result, approximately 83 percent of those that identified themselves as 'Other' also identified with one or more of the alternative sectors as well.

Chapter 3. Environmental Management Drivers

3.1. Introduction

The projected growth of aviation and accompanying environmental effects has changed the priority of some traditional aviation-related environmental issues and resulted in the emergence of some new concerns. This chapter discusses and analyzes the priority of environmental issues and impacts to aviation organizations including those that are currently most important. Where applicable, the analysis and discussion investigates trends by industry sector.

3.2. Priority Environmental Issues or Impacts

Respondents were asked to rate the importance of various environmental issues or impacts to their organization. Rating scores were tallied and the level of importance with the highest percentage of votes for each issue or impact was identified. Figure 3.1 lists those environmental issues with agreement across each of the five sectors as to their level of importance. According to the respondents, these are the environmental issues of highest and medium importance to the aviation industry today. There was no consensus across industry sectors as to the issues or impacts that might be of importance in five or 10 years time, or of those that will never be important.

Figure 3.1: *Areas of environmental concern across all aviation industry sectors.*

Environmental Issue or Impact	**Importance Today**	
	High	*Medium*
Aircraft Noise	✓	
Noise from ground activities		✓
Fuel efficiency	✓	
Financial	✓	
Compliance with laws and regulations	✓	
State/country policies	✓	
Company core values and ethics	✓	
Global climate change	✓	
Non-governmental organizations		✓
Corporate commitment and vision	✓	
Capacity and growth constraints	✓	
Soil and water protection	✓	

Energy management	✓
Materials and chemicals management	✓
Operational efficiency	✓
Customers and other stakeholders' concerns	✓

Note: Agreement was identified through comparison of categories with the highest respondent percentage across all five sectors.

Respondents rated each environmental issue against six levels of importance: very important now, medium important now, likely to be important in 5 years, likely to be important in 10 years, will never be very important, and not applicable. Only one level of importance could be assigned to each environmental issue or impact.

Chapter 4. Approaches to Environmental Management

4.1. Introduction

Aviation organizations are increasingly challenged to meet new market demands in a manner that is environmentally sustainable. In response to this challenge, organizations are using EMS approaches to manage environmental issues. This chapter discusses and analyzes the approaches that aviation organizations are using to manage their environmental issues. Where applicable, the analysis and discussion investigates trends by industry sector.

4.2. Application of EMS Standards or Guidelines

EMS standards or guidelines are employed by 117 or approximately 50 percent of the questionnaire respondents across all five sectors. The number of organizations within each sector that apply EMS standards or guidelines is illustrated below in Figure 4.1.

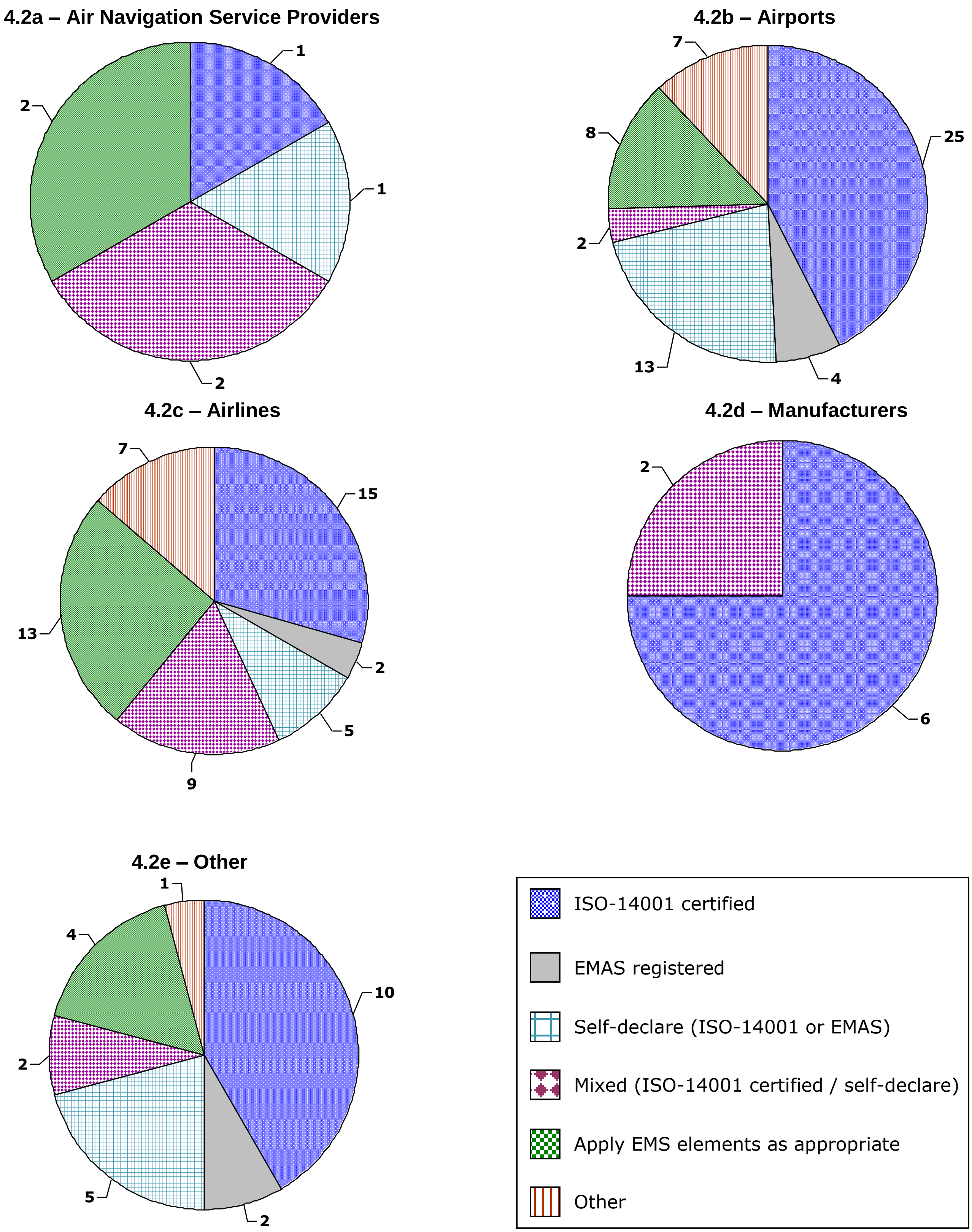
Figure 4.1: *Organizations that use EMS standards or guidelines within each aviation industry sector.*

Aviation Industry Sector Use of EMS	
Air Navigation Service Providers	6
Airlines	42
Airports	54
Manufacturers	8
Other	19
	129

Note [1]: Of the 129 organizations that use EMS standards or guidelines, 117 are unique respondents. 12 respondents were included in multiple sectors.
Note [2]: CAEP received a total of 233 survey responses from across all five sectors.

The types of EMS standards or guidelines used by respondents in each sector are displayed in Figure 4.2 below. The majority of respondents (57 total) in four of the five sectors have implemented an ISO-14001 v2004 certified EMS. Other commonly used EMS standards include the application of organization appropriate EMS elements (27 total) and the implementation of a formal EMS based on ISO-14001 or the Eco-Management Audit Scheme (EMAS) but without third-party certification (24 total). Across all five sectors, eight organizations were registered to EMAS.

Figure 4.2: *EMS approaches to managing environmental issues by aviation industry sector.*



4.3. Scope of EMS

In order to understand the extent of EMS implementation within respondent organizations, survey participants were asked to identify the elements of their organization currently within the scope of their EMS. Figure 4.3 illustrates how much of the respondents organization was included within the scope of their EMS (e.g., is the entire organizations and all its operations included within the EMS scope or are only select facilities or operations covered by the EMS). Most respondents indicated that 100% of their organization (i.e., all facilities and operations) were covered by the scope of their EMS.

Figure 4.3: *The percentage of the organization included in the scope of the EMS.*

Sector	Percentage of the Organization Included in the Scope of the EMS				
	< 30%	*30%-60%*	*60-90%*	*90-100%*	*100%*
ANSPs	1	0	0	0	3
Airports	4	3	1	5	37
Airlines	2	6	4	5	8
Manufacturers	0	0	1	0	4
Other	1	0	0	3	10

Respondents were also asked to identify the activities or operations that they currently include in their organization's EMS. Figure 4.4 lists those functions that were included or excluded from EMS scopes across each of the five sectors. Note that of the 28 activities and operations included in the questionnaire, 'Catering centers' is the only item typically excluded from an EMS's scope.

Figure 4.4: *Activities and operations concurrently included or excluded from the EMS scope across all aviation industry sectors.*

Organization's Activity or Operation	**EMS Scope**	
	Included	*Excluded*
Engineering/maintenance operations	✓	
Catering centers		✓
Facility management	✓	
Staff environmental training	✓	
Organization organizational structure and policies	✓	
Environmental accounting	✓	
Environmental performance criteria	✓	
Environmental auditing	✓	
Energy management	✓	
Soil and water protection	✓	
Waste management	✓	
Materials and chemicals management	✓	
Air quality monitoring	✓	
Noise exposure monitoring	✓	
Ground transportation	✓	
Procurement policies/supplier requirements	✓	
Ecology conservation	✓	

Note [1]: Agreement was identified through comparison of categories with the highest respondent percentage across all five sectors.

Note [2]: An activity or operation was listed as 'Excluded' if the highest respondent percentage across all five sectors was 'Don't know / Not applicable'.

Respondents categorized each function based of the following scope options: included in EMS, likely to be included within 5 years, likely to be included within 10 years, and don't know/not applicable. Only one scope option could be assigned to each activity or operation.

4.4. Other Management Systems In Place

Out of 117 respondents with an EMS, 82 percent have one or more additional management systems in place. The percentage of respondents with either a Safety Management System (SMS) or a Quality Management System (QMS) is high for all sectors (See Figure 4.5). However, in four of the sectors (Airports, Airlines, Manufacturers, and Others) the most common addition to an EMS was a QMS.

Figure 4.5: *Management System types in addition to EMS within each aviation industry sector.*

4.5a – Air Navigation Service Providers

Additional Management System in Place	
Safety Management System (SMS)	67%
Quality Management System (QMS)	50%
Other Management System	17%
No Additional Management System	17%
Note: Percentages based on 6 ANSP responses.	

4.5b – Airports

Additional Management System in Place	
Safety Management System (SMS)	48%
Quality Management System (QMS)	52%
Other Management System	13%
No Additional Management System	26%
Note: Percentages based on 54 Airport responses.	

4.5c – Airlines

Additional Management System in Place	
Safety Management System (SMS)	64%
Quality Management System (QMS)	95%
Other Management System	19%
No Additional Management System	5%
Note: Percentages based on 42 Airline responses.	

4.5d – Manufacturers

Additional Management System in Place	
Safety Management System (SMS)	75%
Quality Management System (QMS)	100%
Other Management System	13%
No Additional Management System	0%
Note: Percentages based on 8 Manufacturer responses.	

4.5e – Others

Additional Management System in Place	
Safety Management System (SMS)	37%
Quality Management System (QMS)	74%
Other Management System	11%
No Additional Management System	21%
Note: Percentages based on 19 Other responses.	

Approximately 51 percent of respondents with additional management system(s) in place have integrated or coordinated it with their EMS. Most respondents with integrated systems suggested the greatest benefits to be:

1. the sharing of system procedures and processes, which helps to avoid duplications of effort and increase efficiency; and

2. the ability to manage diverse operations in a more integrated manner.

Chapter 5. Performance Monitoring and Communication

5.1. Introduction

As aviation organizations adapt to meet industry demands in an environmentally sustainable way, demonstrating and communicating environmental performance to stakeholders is becoming increasingly important. This chapter discusses and analyzes the value of EMS in assisting aviation organizations to manage a broad range of environmental issues, impacts, and regulations. It also describes the types of environmental targets that aviation organizations set, the approaches used to measure performance, and the methods that are employed to communicate their EMS. Where applicable, the analysis and discussion investigates trends by industry sector.

5.2. Performance Monitoring

Respondents that have an EMS in place were asked to rate how helpful their EMS is in managing and controlling their organization's various environmental issues. Figure 5.1 lists those environmental issues with consensus across each of the five sectors as to their level of helpfulness. According to the respondents, these are the areas of environmental concern in which EMS is most helpful to the aviation industry today. There was no consensus across industry sectors as to the helpfulness of EMS in managing environmental issues of medium importance today, those that might be of importance in five or 10 years time, or of those areas in which EMS will never be helpful.

Figure 5.1: *Consensus areas of EMS helpfulness towards managing and controlling environmental concerns across all aviation industry sectors.*

Environmental Issue or Impact	Very Helpful Today
Compliance with laws and regulations	✓
State/country policies	✓
Company core values and ethics	✓
Corporate image	✓
Soil and water protection	✓
Waste management	✓
Energy management	✓

Note: Agreement was identified through comparison of categories with the highest respondent percentage across all five sectors.

Respondents rated each environmental issue against six levels of EMS helpfulness: very helpful now, medium helpful now, likely to be helpful in 5 years, likely to be helpful in 10 years, will never be very helpful, and not applicable. Only one level of helpfulness could be assigned to each environmental issue or impact.

Respondents indicated that one of the most important reasons why environmental performance is measured is to ensure compliance. The questionnaire asked participants to list the five most important environmental regulations in which their organization's EMS ensures compliance. As a result of global participation in the questionnaire, various environmental regulations were identified as important and there was no clear consensus on which laws were the most significant. The results were therefore categorized into areas of environmental concern, which were then tallied and ranked to identify the top five areas in which the survey respondents ensure compliance (Figure 5.2).

Figure 5.2: *Top five areas of environmental regulatory concern.*

Important Environmental Regulation Areas	
Hazardous/solid waste	54%
Water	40%
National environmental regulations	38%
Air	34%
Noise	26%

Note: Percentages based on 115 respondents.

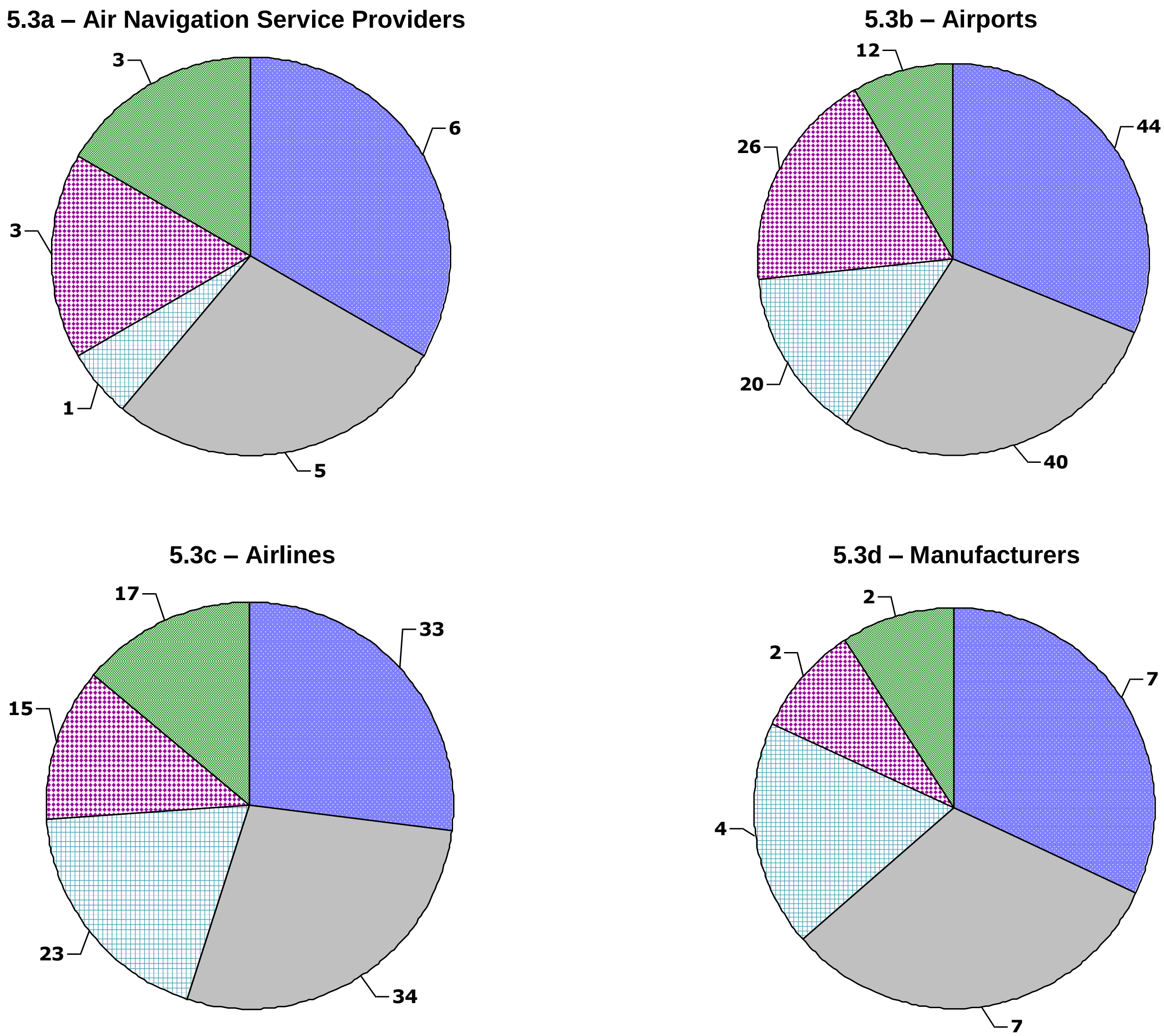
The management and disposal of hazardous and solid waste is the most important environmental area in which respondent organizations ensure compliance. Second, legislation that regulates the quality, management, and use of storm water, waste water, and drinking water was important to 40 percent of questionnaire respondents. Many respondents indicated that they ensure compliance with the national environmental legislation in place in each country in which their organization operates. The national environmental legislation that was identified by respondents typically regulated general environmental concerns such as environmental protection and conservation. The fourth most important regulated environmental area was the quality and management of air emissions, in particular carbon dioxide. Lastly, respondents indicated that regulations that focused on noise were also important.

In addition to compliance, questionnaire respondents stated that other important reasons to measure environmental performance include the tracking and monitoring of progress towards achievement of environmental objectives and for the purpose of reporting performance to stakeholders and the public. Respondent organizations typically measure performance through environmental audits and the use of key performance indicators. The environmental targets set by questionnaire respondents are directly aligned with the environmental areas in which organizations ensure compliance. In general, respondents are looking to reduce their consumption of energy, waste, water, emissions, and noise. On average, environmental targets and objectives are set no more than five years into the future.

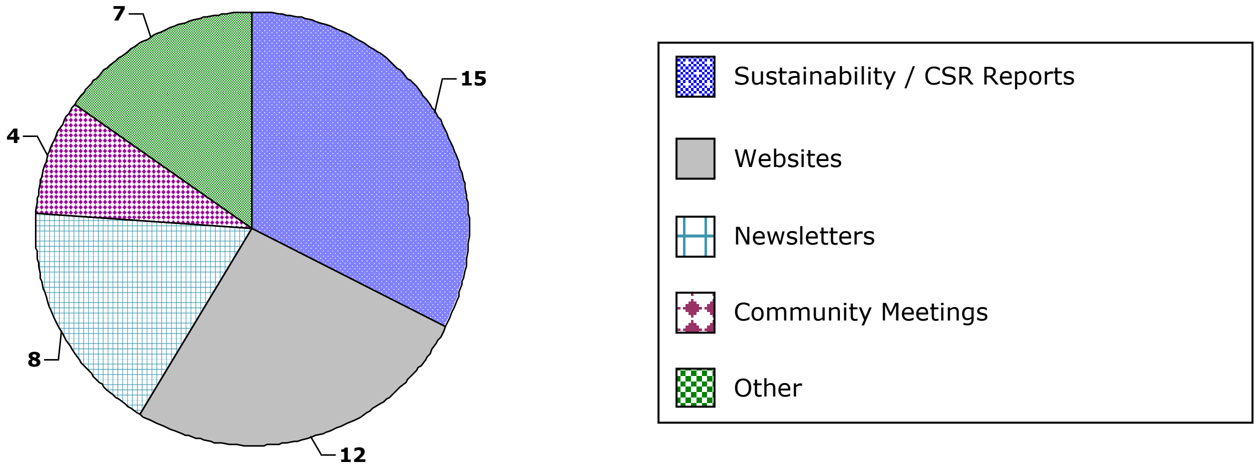
5.3. Communication Methods

As depicted in Figure 5.3 below, the most common methods of communicating environmental performance across all five sectors are through the use of sustainability or corporate social responsibility (CSR) reports and through the organization’s website. The third most common method of external communication employed by Airport and ANSP respondents is to use community meetings as a forum for informing stakeholders and the public. In contrast, Manufacturer, Airline, and Other respondents prefer the use of newsletters over community meetings. In all sectors there were some organizations who listed other means of communicating environmental performance, these include: presentations at conferences, internal meetings, press releases, and magazines and other publications.

Figure 5.3: *Methods for communicating environmental performance used by organizations within each aviation industry sector that have implemented an EMS.*



5.3e – Other



Chapter 6. Implementation and Maintenance

6.1. Introduction

A wide range of approaches can be used to implement an EMS depending on the nature of the organization's operations and future plans. This chapter discusses and analyzes the resources and time needed for EMS implementation, including training. It also discusses the resources needed to operate and maintain an EMS, as well as the length of time the organization has operated their EMS. Where applicable, the analysis and discussion investigates trends by industry sector.

6.2. EMS Implementation

Respondents were asked to indicate when their EMS was implemented as well as the length of time they felt was necessary to successfully implement the system within their organization. The same trends were found among all five sectors; and therefore responses were aggregated at the industry level. Figure 6.1 shows EMS implementation to have been relatively consistent within the industry for the past 10 years.

Figure 6.1: *Average length of time EMS has been in place across all aviation industry sectors.*

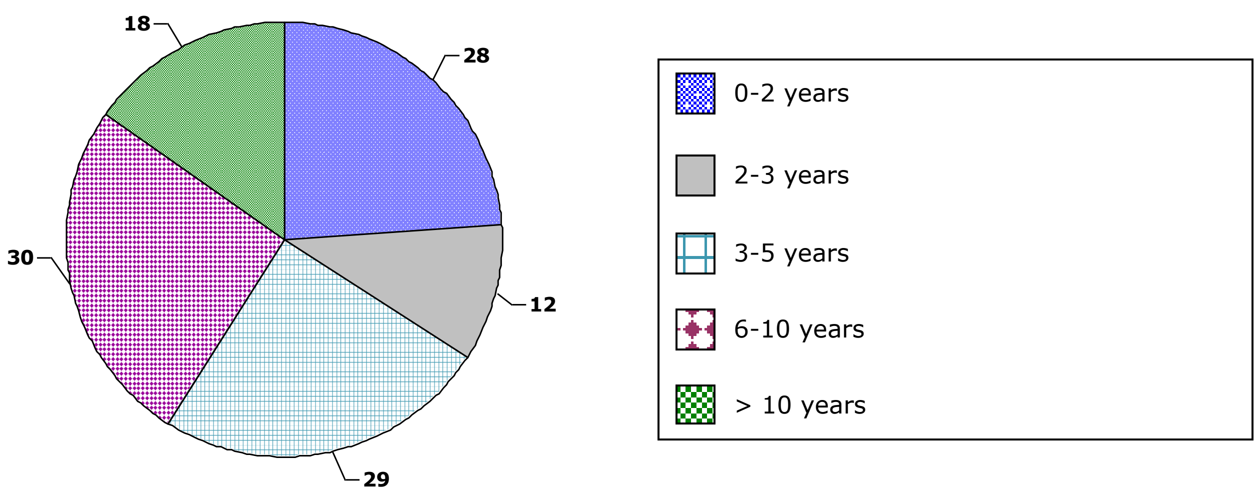


Figure 6.2 below indicates that most organizations (46 total) required 6–12 months to fully develop and implement their EMS. Very few organizations (8 total) were able to accomplish this task in less than six

months, and many (63 total) needed one to two years to fully deploy their systems. EMS implementation typically takes longer in large organizations and those with complicated operations. Approximately, 71 percent of the 117 respondents with an EMS in place sought outside assistance from a consulting or contracting firm in order to implement the system.

Figure 6.2: *Average time taken to implement EMS across all aviation industry sectors.*

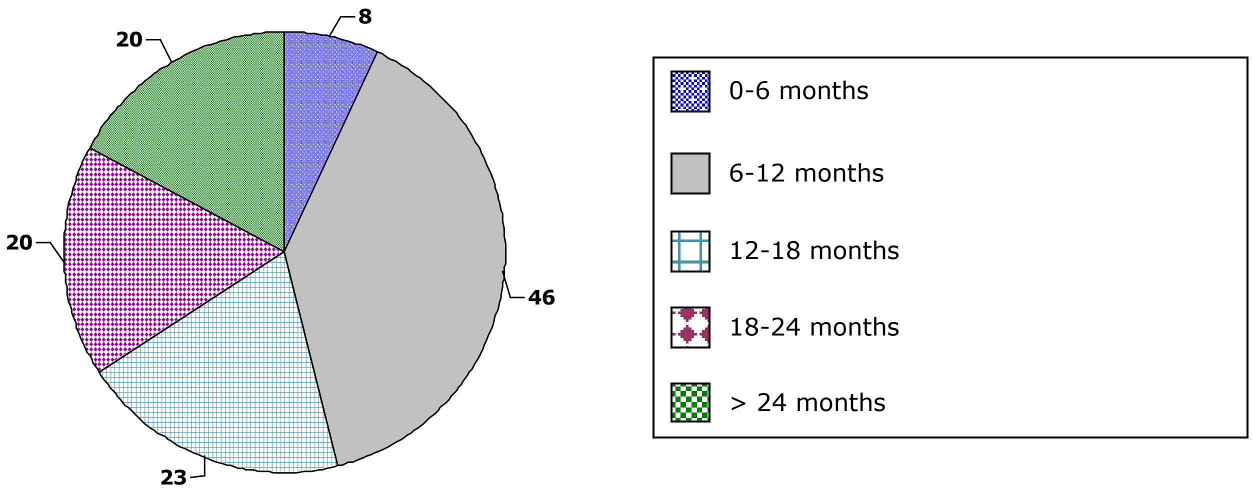


Figure 6.3 provides a rough estimate of the average level of resources necessary for EMS implementation within each of the five sectors. Note that the averages for each sector are based on the total number of question respondents and do not necessarily reflect all questionnaire respondents for each sector. The estimates provided by respondents on the length of time necessary for implementation are higher than those identified in Figure 6.2. The Airline, Airport, and Other sector results indicate that implementation takes approximately 14–15 months. Manufacturers and ANSPs provided estimated longer implementation times with ANSPs estimating about 3.5 years for implementation. The results indicate that, on average, a minimum of five employees are required during EMS implementation. Both Airports and Manufacturers provided larger estimates of 26 and 34 employees necessary for implementation, respectively. All five sectors estimated the need for at least two additional employees during EMS implementation with the Manufacturing sector respondents going so far as to estimate an average need for 20 additional staff. Within each sector, the estimates for the number of employees necessary for implementation varied by organization size.

Figure 6.3: *Average resource use for EMS implementation within each aviation industry sector.*

6.3a – Air Navigation Service Providers

Implementation Resource Average	
Implementation time (months)	41.0
Employees used	5.7
Employees hired for implementation	4.3
Contractor support costs (USD)	$544,429
Equipment costs (USD)	$10,000
Certification / registration costs (USD)	$100,000

Note: Averages based on 6 ANSP responses.

6.3b – Airports

Implementation Resource Average	
Implementation time (months)	15.3
Employees used	26.3
Employees hired for implementation	2.3
Contractor support costs (USD)	$62,950
Equipment costs (USD)	$209,114
Certification / registration costs (USD)	$9,966

Note: Averages based on 54 Airport responses.

6.3c – Airlines

Implementation Resource Average	
Implementation time (months)	13.9
Employees used	9.5
Employees hired for implementation	2.9
Contractor support costs (USD)	$51,542
Equipment costs (USD)	$19,699
Certification / registration costs (USD)	$12,976

Note: Averages based on 42 Airline responses.

6.3d – Manufacturers

Implementation Resource Average	
Implementation time (months)	21.4
Employees used	33.5
Employees hired for implementation	19.6
Contractor support costs (USD)	$42,500
Equipment costs (USD)	$0
Certification / registration costs (USD)	$120,000

Note: Averages based on 8 Manufacturer responses.

6.3e – Others

Implementation Resource Average	
Implementation time (months)	15.2
Employees used	11.2
Employees hired for implementation	5.8
Contractor support costs (USD)	$89,591
Equipment costs (USD)	$33,344
Certification / registration costs (USD)	$9,778

Note: Averages based on 19 Other responses.

Contract support costs ranged between $42,000–$90,000 for four of the five sectors (Airports, Airlines, Manufacturers, and Others). ANSP respondents indicated an average cost for contractor support of more than $500,000. Estimates for the average cost of equipment ranged from $10,000–$34,000 for three of the five sectors (ANSPs, Airlines, and Others). Manufacturer sector respondents did not provide an estimate for their equipment costs and Airports sector respondents estimated an average equipment cost of $209,114. EMS certification and registration costs for three of the five sectors (Airports, Airlines and Others) ranged from $9,700–$13,000. ANSP and Manufacturer sector respondents estimate average EMS certification and registration costs to be much higher at $100,000 and $120,000 respectively. However, it is important to note that the monetary figures provided as part of the survey responses were rough estimates and caution should therefore be taken when using them to represent industry or sector trends.

6.3. EMS Maintenance

Figure 6.4 provides a rough average estimate of the level of resources necessary for EMS operation and maintenance (O&M) for each of the five sectors. Note that the averages for each sector are based on the total number of question respondents and do not necessarily reflect all questionnaire respondents for each sector. For three of the five sectors (Airports, Airlines, and Other), time necessary for operation and maintenance ranges from 1–2 years. Estimates provided by ANSP and Manufacturer sector respondents were on both sides of this range with Manufacturers on average spending less than six months on O&M and ANSPs needing three years. As for the number of employees needed for EMS O&M, the estimates varied by sector and are as follows: five for ANSPs, 28 for Airports, 15 for Airlines, 30 for Manufacturers, and 16 for Others.

Figure 6.4: *Average resource use for EMS O&M within each aviation industry sector.*

6.4a – Air Navigation Service Providers

O&M Resource Average	
O&M time (months)	36.0
Employees used	5.0
Contractor support costs (USD)	$275,000
Equipment costs (USD)	$10,000
Certification / registration costs (USD)	$36,653

Note: Averages based on 6 ANSP responses.

6.4b – Airports

O&M Resource Average	
O&M time (months)	22.2
Employees used	27.7
Contractor support costs (USD)	$22,577
Equipment costs (USD)	$21,554
Certification / registration costs (USD)	$5,020

Note: Averages based on 54 Airport responses.

6.4c – Airlines

O&M Resource Average	
O&M time (months)	17.0
Employees used	14.8
Contractor support costs (USD)	$14,500
Equipment costs (USD)	$36,407
Certification / registration costs (USD)	$7,704

Note: Averages based on 42 Airline responses.

6.4d – Manufacturers

O&M Resource Average	
O&M time (months)	3.8
Employees used	29.5
Contractor support costs (USD)	$5,000
Equipment costs (USD)	$25,000
Certification / registration costs (USD)	$77,000

Note: Averages based on 8 Manufacturer responses.

6.4e – Others

O&M Resource Average	
O&M time (months)	14.3
Employees used	16.0
Contractor support costs (USD)	$63,511
Equipment costs (USD)	$30,000
Certification / registration costs (USD)	$6,636

Note: Averages based on 19 Other responses.

The range of contract support costs were estimated to be $5,000–$22,577 for three out of five sectors (Airports, Airlines, and Manufacturers). Other sector respondents estimate an average cost of $63,500 for contract support and ANSPs estimated an average cost of $275,000. The cost of equipment for four out of five sectors (Airports, Airlines, Manufacturers, and Others) was estimated to be between $21,000–$36,000. Equipment costs for ANSPs were estimated to be $10,000 on average. Lastly, three out of five sectors (Airports, Airlines and Others) estimate average EMS certification and registration costs to be in the range of $5,000–$7,704. Manufacturers and ANSPs had higher estimates for EMS certification and registration costs. Manufacturers estimated $77,000 for EMS certification and registration costs and ANSPs estimated about $37,000. Once again, it is important to note that the monetary figures provided were rough estimates and caution should be taken in using the data as representative of industry or sector trends.

Staff training is necessary for both EMS implementation and maintenance. Questionnaire respondents were asked to indicate the types of staff training required for their EMS. The training of management and office personnel and engineering and maintenance staff had the highest respondent percentages across all five sectors. Sector differences were apparent in the additional types of training that were required for EMS implementation and maintenance (Figure 6.5). For example, airlines required both ground operations personnel and cabin crew training, airports required ground operations personnel training, and manufacturers required manufacturing personnel training.

Figure 6.5: *Staff training required as a result of the EMS within each aviation industry sector.*

6.5a – Air Navigation Service Providers

Staff Requiring EMS Training	
Management & office staff	80%
Engineering & maintenance staff	80%
Manufacturing staff	0%
Ground operations staff	20%
Air traffic controller staff	40%
Cabin crew staff	0%
Other staff	40%

Note: Percentages based on 5 ANSP responses.

6.5b – Airports

Implementation Resource Average	
Management & office staff	91%
Engineering & maintenance staff	83%
Manufacturing staff	11%
Ground operations staff	39%
Air traffic controller staff	9%
Cabin crew staff	0%
Other staff	17%

Note: Percentages based on 46 Airport responses.

6.5c – Airlines

Implementation Resource Average	
Management & office staff	84%
Engineering & maintenance staff	76%
Manufacturing staff	8%
Ground operations staff	63%
Air traffic controller staff	8%
Cabin crew staff	45%
Other staff	47%

Note: Percentages based on 38 Airline responses.

6.5d – Manufacturers

Implementation Resource Average	
Management & office staff	88%
Engineering & maintenance staff	88%
Manufacturing staff	88%
Ground operations staff	38%
Air traffic controller staff	0%
Cabin crew staff	0%
Other staff	25%

Note: Percentages based on 8 Manufacturer responses.

6.5e – Others

Implementation Resource Average	
Management & office staff	29%
Engineering & maintenance staff	24%
Manufacturing staff	12%
Ground operations staff	24%
Air traffic controller staff	0%
Cabin crew staff	6%
Other staff	12%
Note: Averages based on 17 Other responses.	

Chapter 7. Benefits and Challenges

7.1. Introduction

While organizations differ, there are lessons-learned from every EMS implementation. This chapter discusses and analyzes the benefits and challenges perceived by respondents to implementing EMS. Analysis and discussion of trends has been aggregated for all sectors.

7.2. Implementation Challenges

Respondents, regardless of sector, identified many of the same challenges with EMS implementation. Figure 7.1 outlines the top three challenges experienced by questionnaire respondents. The greatest challenges identified were the amount of resources and the degree of culture change necessary for successful EMS implementation. Respondents stated that it was difficult to alter employee behavior towards incorporating environmental considerations and responsibilities into decision making and day to day operations.

Figure 7.1: *Top three EMS implementation challenges.*

EMS Implementation Challenges	
Resources (time, finances)	26%
Culture change	26%
Employee awareness / training	23%
Management commitment	16%
Note: Percentages based on 110 survey respondents.	

Another common challenge respondents faced was adequately training employees to be aware of the EMS and their responsibilities with regards to system maintenance. Lastly, lack of management commitment was cited as the third most common challenge among respondents. In addition to those included in Figure 7.1, respondents identified EMS alignment within the larger organization and recordkeeping requirements during EMS implementation as further implementation challenges. It is important to note that the challenges identified above are often the most common issues with EMS implementation.

7.3. Benefits of EMS Implementation

The three most common benefits of EMS implementation are illustrated below in Figure 7.2. Respondents indicated that the greatest benefit of EMS implementation is that it enhances the reputation and image of the organization. In addition, respondents noted that this enhanced reputation improved their relationship with stakeholders. Another benefit of EMS implementation is improved compliance with environmental regulations. Also, since EMS is a proactive approach to environmental management, risk to the organization is mitigated. Lastly, respondents cited that improving the environment, or lessening their organization's impact on the environment, was an important benefit of EMS implementation. Other benefits of EMS implementation included the ability to track environmental performance, a reduction in costs, and an increase in awareness and efficiency.

Figure 7.2: *Three most frequently cited benefits of EMS implementation.*

EMS Implementation Benefits	
Enhance reputation / image	34%
Enhance compliance / mitigate risk	33%
Environmental improvements	25%
Note: Percentages based on 110 survey respondents.	

7.4. Trade-off Analysis

According to the sector respondents, the benefits of EMS implementation far outweigh the implementation and maintenance challenges. Approximately 96 percent of questionnaire respondents recommend that other organizations establish EMS. Many respondents stated that they would be willing to share some of their EMS materials including environmental policies, environmental/sustainability reports, performance metrics, and objectives and targets. However, organizations were not willing to share EMS documentation that may contain proprietary information such as audit reports and complete EMS Manuals.

Chapter 8. Organizations without an EMS

8.1. Introduction

Some organizations have not implemented an EMS, but do have other environmental programs in place to manage their environmental issues. This chapter discusses and analyzes responses from those organizations that have not implemented an EMS. It reviews the approaches that are used to manage environmental issues and impacts including those that are common to EMS and it analyzes the environmental issues and impacts that are most important to these organizations now. In addition, it investigates the metrics and targets that are established to measure performance and the types of guidance that would be helpful to assist them in implementing an EMS. Where applicable, the analysis and discussion investigates trends by industry sector.

8.2. Environmental Program Elements or Principles

A total of 116 questionnaire respondents do not apply EMS standards or guidelines. However, these respondents have environmental programs in place that have many of the same elements or principles required for an EMS. Respondents without a formal EMS were asked to identify whether or not EMS elements were included in their environmental program. Figure 8.1 illustrates the percentage of respondents, by sector, whose environmental program includes certain elements or principles consistent with EMS.

Figure 8.1: *Environmental program elements of organizations that do not apply EMS standards or guidelines.*

8.1a – Air Navigation Service Providers

Environmental Program Elements	
Environmental Vision / Policy	63%
Goals, Objectives or Targets	44%
Management Programs	19%
Operational Controls	75%
Environmental Metrics	19%
Performance Reporting	38%
External Communication Programs	25%
Employee Awareness Training Programs	38%
Compliance Audits / Inspections	31%
Systems / Process Audits	31%
Emergency Preparedness	38%
Management Structure or Framework	13%
Top Management Performance Reviews	13%

Note: Percentages based on 16 ANSP responses.

8.1b – Airports

Environmental Program Elements	
Environmental Vision / Policy	68%
Goals, Objectives or Targets	66%
Management Programs	58%
Operational Controls	84%
Environmental Metrics	53%
Performance Reporting	63%
External Communication Programs	39%
Employee Awareness Training Programs	61%
Compliance Audits / Inspections	61%
Systems / Process Audits	39%
Emergency Preparedness	68%
Management Structure or Framework	50%
Top Management Performance Reviews	34%

Note: Percentages based on 38 Airport responses.

8.1c – Airlines

Environmental Program Elements	
Environmental Vision / Policy	89%
Goals, Objectives or Targets	74%
Management Programs	51%
Operational Controls	63%
Environmental Metrics	34%
Performance Reporting	49%
External Communication Programs	37%
Employee Awareness Training Programs	57%
Compliance Audits / Inspections	60%
Systems / Process Audits	37%
Emergency Preparedness	57%
Management Structure or Framework	34%
Top Management Performance Reviews	26%

Note: Percentages based on 35 Airline responses.

8.1d – Manufacturers

Environmental Program Elements	
Environmental Vision / Policy	100%
Goals, Objectives or Targets	100%
Management Programs	50%
Operational Controls	100%
Environmental Metrics	100%
Performance Reporting	100%
External Communication Programs	100%
Employee Awareness Training Programs	100%
Compliance Audits / Inspections	100%
Systems / Process Audits	50%
Emergency Preparedness	100%
Management Structure or Framework	100%
Top Management Performance Reviews	50%

Note: Percentages based on 2 Manufacturer responses.

8.1e – Others

Environmental Program Elements	
Environmental Vision / Policy	82%
Goals, Objectives or Targets	73%
Management Programs	64%
Operational Controls	86%
Environmental Metrics	41%
Performance Reporting	64%
External Communication Programs	50%
Employee Awareness Training Programs	77%
Compliance Audits / Inspections	77%
Systems / Process Audits	55%
Emergency Preparedness	77%
Management Structure or Framework	64%
Top Management Performance Reviews	50%

Note: Percentages based on 22 Other responses.

It is evident from the data that respondents across all five sectors have many elements of an EMS in place. Respondent percentages were high across all sectors for the following elements:

- Environmental vision/policy;
- Environmental goals, objectives or targets;
- Operational controls;
- Employee awareness training programs;
- Compliance audits/inspections; and
- Emergency preparedness.

On average, top management performance reviews had the lowest respondent percentage across all five sectors. This is important to note because management commitment is imperative for organizations to effectively manage their environmental impacts. Organizations with an EMS indicated that management commitment is one of the biggest challenges of EMS implementation. Lastly, it is important to note that there were only two respondents from the manufacturing sector.

8.3. Performance Monitoring

Respondents that use an environmental program rather than a formal EMS were asked to rate how helpful it is in managing and controlling 28 specific environmental issues or impacts. Figure 8.2 includes five tables that list those environmental issues most commonly identified as helpful today by respondents in each sector. Generally, there was not a strong level of agreement on the level of helpfulness across all five industry sectors.

Although there was no agreement across the aviation industry, four out of five sectors (ANSPs, Airlines, Manufacturers, and Others) agreed that their environmental programs were helpful in managing and controlling compliance with laws and regulations today. Four out of five sectors (ANSPs, Airports, Airlines, and Others) also agreed that their environmental program was helpful in managing customer and other stakeholder concerns, fuel efficiency, financial, and company core values and ethics. (Note: Only two respondents were identified as part of the manufacturer sector.)

Figure 8.2: *Areas of environmental concern in which use of an environmental program is seen as helpful by organizations that do not apply EMS standards or guidelines for management.*

8.2a – Air Navigation Service Providers

Environmental Issue or Impact	Helpful Today		Not Applicable
	High	*Medium*	
Aircraft Noise	✓		
Emissions from ground activities			✓
Noise from ground activities			✓
Fuel efficiency	✓		
Financial		✓	
Compliance with laws and regulations	✓		
State/country policies	✓		
Competitive pressures			✓
Company core values and ethics		✓	
Media pressure			✓
Corporate image		✓	
Local community concerns			✓
Non-governmental organizations			✓
Capacity and growth constraints		✓	
Soil and water protection			✓
International public perceptions		✓	
Waste management		✓	
Materials and chemicals management			✓
International policy		✓	
Customers and other stakeholders' concerns	✓		
Shareholders appreciation or rating agencies			✓

<u>*Note*</u>: *Areas of helpfulness determined through identification of categories with single highest respondent percentage within the ANSP sector.*

8.2b – Airports

Environmental Issue or Impact	Helpful Today	Helpful in 5 years
	Medium	
Aircraft Emissions	✓	
Noise from ground activities		✓
Fuel efficiency	✓	
Financial	✓	
Competitive pressures	✓	
Company core values and ethics	✓	
Media pressure	✓	
Local air quality	✓	
Energy management	✓	
Operational efficiency	✓	
Customers and other stakeholders' concerns	✓	

<u>*Note*</u>: *Areas of helpfulness determined through identification of categories with single highest respondent percentage within the Airport sector.*

8.2c – Airlines

Environmental Issue or Impact	Helpful Today	
	High	*Medium*
Aircraft Emissions	✓	
Aircraft Noise		✓
Emissions from ground activities		✓
Noise from ground activities		✓
Fuel efficiency	✓	
Financial	✓	
Compliance with laws and regulations	✓	
State/country policies	✓	
Competitive pressures		✓
Company core values and ethics	✓	
Media pressure		✓
Corporate image	✓	
Ecological conservation	✓	
Local community concerns		✓
Global climate change	✓	
Non-governmental organizations		✓
Corporate commitment and vision	✓	
Capacity and growth constraints		✓
Soil and water protection		✓
International public perceptions		✓
Waste management	✓	
Materials and chemicals management		✓
Operational efficiency	✓	
International policy	✓	
Customers and other stakeholders' concerns	✓	

Note: *Areas of helpfulness determined through identification of categories with single highest respondent percentage within the Airline sector.*

8.2d – Manufacturers

Environmental Issue or Impact	Helpful Today	Not Applicable
	High	
Compliance with laws and regulations	✓	
Non-governmental organizations		✓

Note [1]: *Areas of helpfulness determined through identification of categories with single highest respondent percentage within the Manufacturer sector.*

Note [2]: *Only 2 of the responses that CAEP received were from organizations that identified themselves as manufacturers without an EMS currently in place.*

8.2e – Others

Environmental Issue or Impact	Helpful Today	
	High	*Medium*
Aircraft Emissions		✓
Aircraft Noise	✓	
Noise from ground activities		✓
Fuel efficiency	✓	
Financial	✓	
Compliance with laws and regulations	✓	
State/country policies	✓	
Competitive pressures	✓	
Company core values and ethics	✓	
Media pressure	✓	
Corporate image	✓	
Ecological conservation	✓	
Local community concerns	✓	
Local air quality	✓	
Non-governmental organizations		✓
Capacity and growth constraints		✓
Soil and water protection	✓	
International public perceptions	✓	
Waste management	✓	
Energy management	✓	
Materials and chemicals management	✓	
Operational efficiency	✓	
Customers and other stakeholders' concerns	✓	
Shareholders appreciation or rating agencies	✓	

Note: Areas of helpfulness determined through identification of categories with single highest respondent percentage within the Other sector.

Respondents rated each environmental issue against six levels of environmental program helpfulness: very helpful now, medium helpful now, likely to be helpful in 5 years, likely to be helpful in 10 years, will never be very helpful, and not applicable. Only one level of helpfulness could be assigned to each environmental issue or impact.

Similar to respondent organizations with an EMS, respondents without an EMS indicated that it is important to measure environmental performance to ensure compliance. In addition, respondents also indicated that it is important to minimize the organization's impact on the environment. Environmental performance is typically measured through the continuous monitoring and measurement of specific elements important to the organization. In addition, performance is also measured through yearly reviews and inspections as well as by number of incidents that occur per year. The environmental targets set by respondent organizations tend to focus on the reduction of water, fuel, energy, and waste consumption.

Respondents without a formal management system were asked to list the five most important environmental regulations with which their organization's environmental program helps ensure compliance. As a result of having questionnaire respondents from all over the world, various environmental regulations were identified as important, and there was no clear consensus on specific legislation. As with the analysis performed on respondents who have an EMS in place (Section 5.1 of this report), results were categorized into areas of environmental concern, which were then tallied and ranked to identify the top five areas respondents without an EMS ensure compliance (Figure 8.11)

Figure 8.11: *Five most frequently cited areas of environmental regulatory concern.*

Important Environmental Regulation Areas	
Hazardous/solid waste	54%
Air	49%
Water	47%
Noise	39%
National environmental regulations	17%

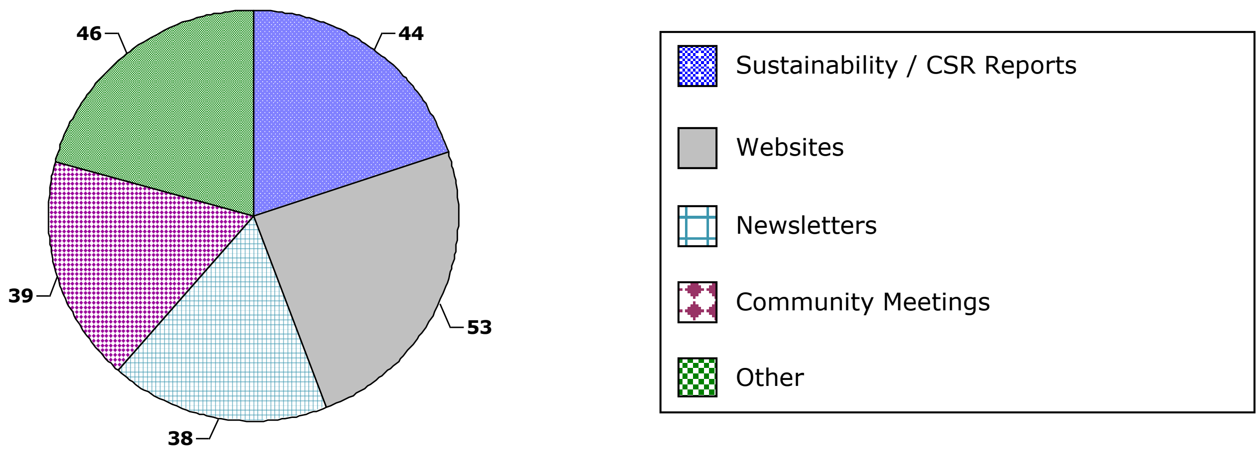
Note: Percentages based on 87 respondents.

The five environmental areas identified as important by respondents without an EMS are identical to those identified by organizations with an EMS. The management and disposal of hazardous and solid waste is the greatest priority to organizations with and without an EMS. Second, legislation that regulates the quality and management of air emissions, in particular carbon dioxide was important to 49 percent of questionnaire respondents. The third most important environmental area concerns the quality, management, and use of storm water, waste water, and drinking water. Managing the level of noise was also deemed important by all five sectors. Lastly, a few respondents indicated that they ensure compliance with other types of country specific national environmental legislation.

8.4. Communication Methods

Respondents were asked to identify the methods used by their organization to communicate about its environmental program. As the same trends were found among all five sectors, the results were aggregated at the industry level. Figure 8.12 provides a breakdown of the communication methods used by respondent organizations with an environmental program in place, but no formal EMS framework.

Figure 8.12: *Methods used by organizations across the aviation industry that have not implemented an EMS for communicating the performance of their environmental program.*



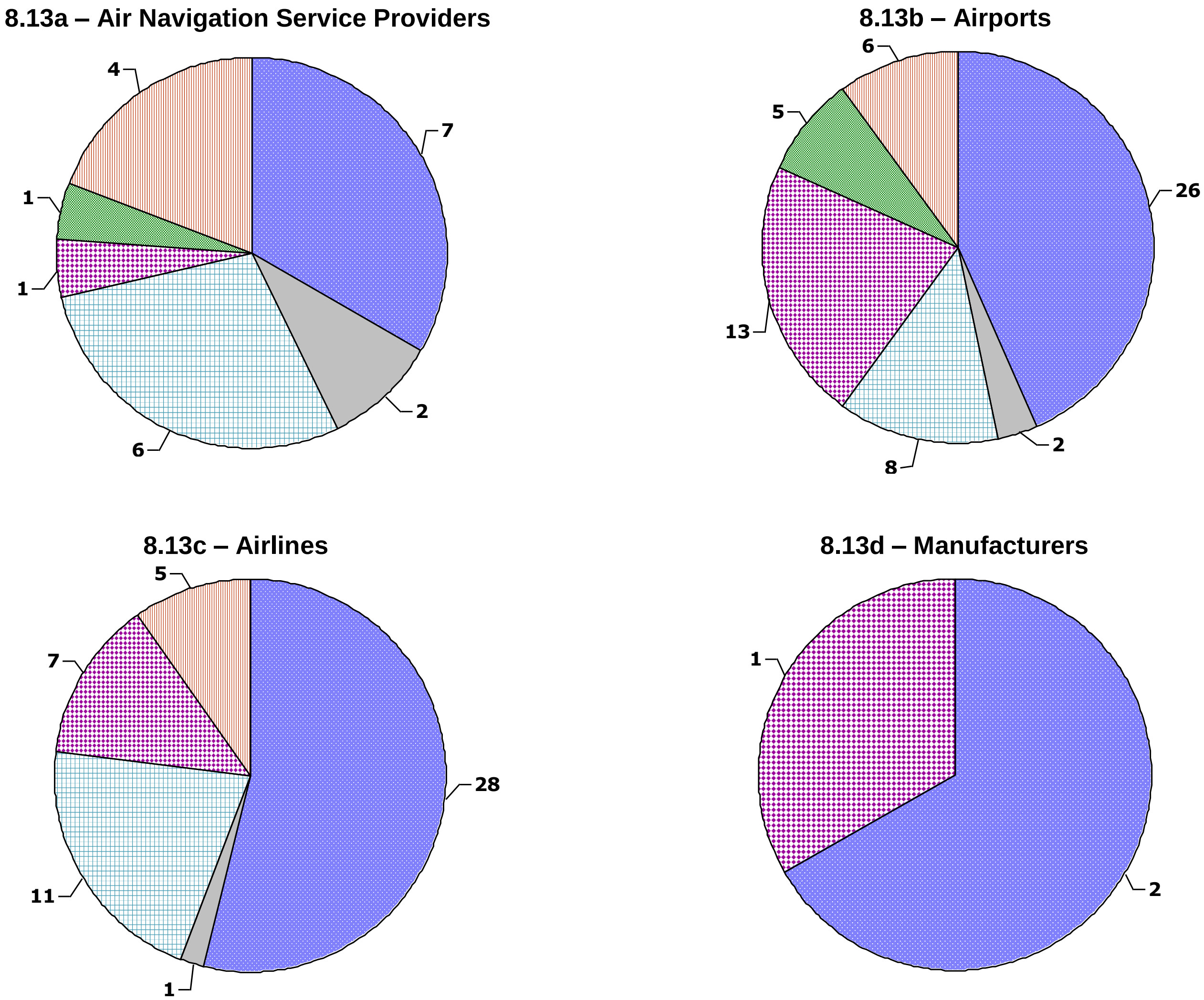
It is evident that all the communication methods outlined in the figure above are applied fairly consistently among the respondents. While the use of websites appears to be the most common means of communication, other methods identified include: posters and brochures, internal meetings, presentations at seminars, and email.

8.5. EMS Application and Development Issues

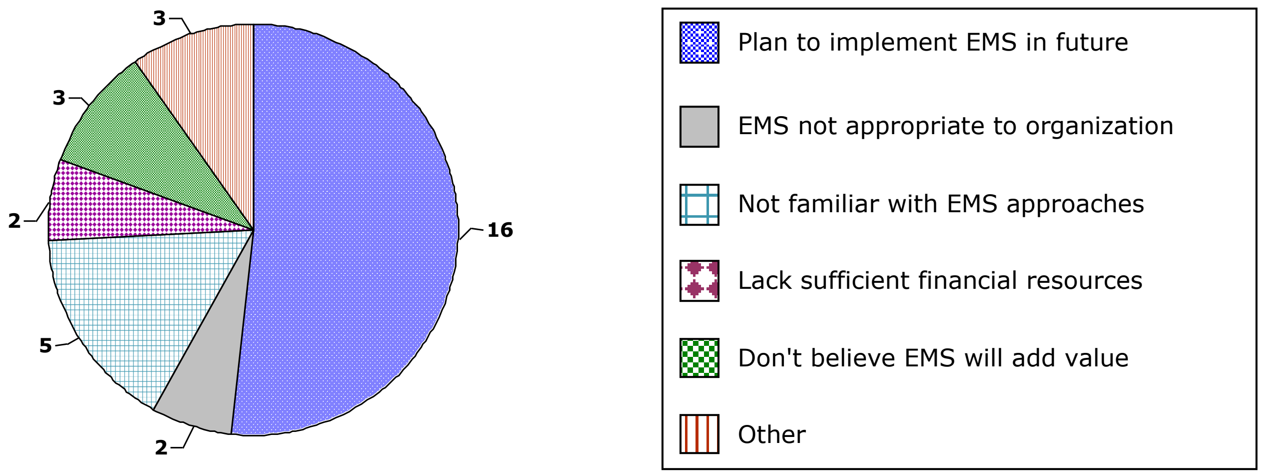
A variety of reasons exist as to why organizations do not apply EMS standards or guidelines. According to the questionnaire's respondents, most (79 total) are planning to implement EMS in the future. Airlines (28 in total) and airports (26 in total) make up the majority of respondents who are planning to implement EMS in the future.

The reasons why respondent organizations across the aviation industry do not apply EMS standards or guidelines are outlined below in Figure 8.13. The most frequent reason for not implementing an EMS is that the organization is not familiar with the EMS approach. Of the five sectors, airlines (11 in total) and airports (8 in total) had the highest response rate for not being familiar with EMS approaches.

Figure 8.13: *Primary reasons for not applying EMS guidelines or standards cited by organizations within each aviation industry sector.*



8.13e – Other



Of the 116 respondent organizations that do not apply EMS standards or guidelines, 79 plan to implement an EMS in the future. Respondents were asked to list those environmental issues their organization would focus on if they were to implement an EMS. Figure 8.14 outlines the top five environmental issues in which respondent organizations would focus their organization's EMS.

Figure 8.14: *Top five environmental issues for inclusion in future EMS.*

Important Environmental Issues	
Air emissions	73%
Hazardous/solid waste	51%
Noise	50%
Fuel efficiency	30%
Energy	23%

Note: Percentages based on 86 respondents.

The environmental issues identified in figure 8.14 closely resemble the list of important regulated environmental areas in Figure 8.11. According to survey respondents, air emissions are the most important issue on which to focus their organization's EMS. Other important elements to focus on include the consumption of fuel and energy.

In order to become more familiar with EMS, respondent organizations have requested guidance to help assist with EMS implementation. Figure 8.15 illustrates the types of CAEP guidance requested by respondents.

Figure 8.15: *Usefulness of CAEP guidance types in assisting aviation industry organizations with EMS implementation.*

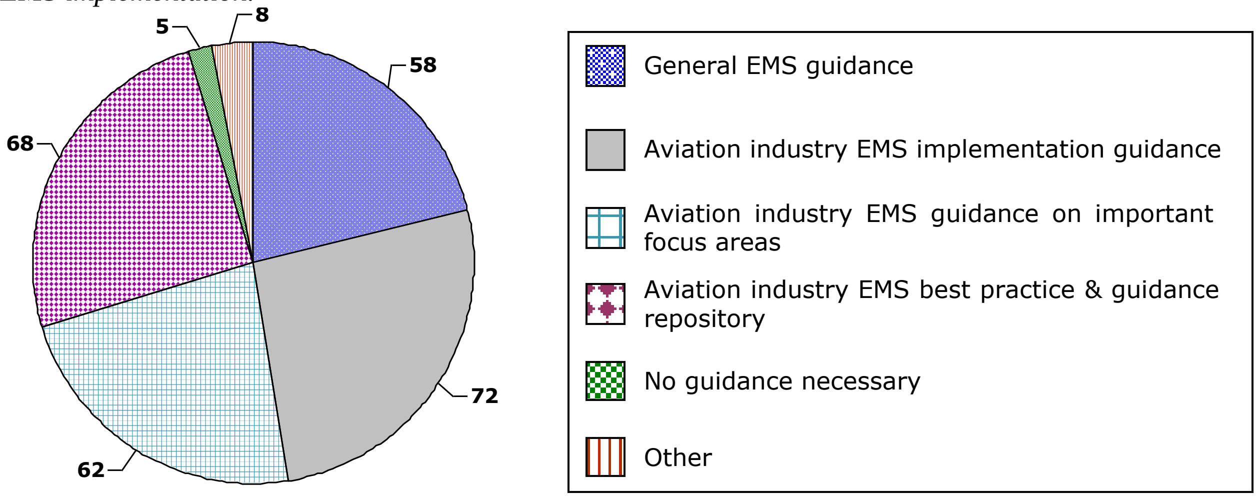


Figure 8.15 indicates that respondents thought that all the guidance materials suggested by the questionnaire could be useful in assisting them with EMS implementation. However, the most useful type of guidance that ICAO-CAEP could provide appears to be aviation industry EMS implementation guidance.

Chapter 9. Recommendations

The following two recommendations are based on information summarized in the report above and input from CAEP TG members. These recommendations focus on increasing awareness of EMS principles and best practices in the aviation sector and establishing practical guidance to assist those states and organizations that chose to use EMS to enhance the way they manage environmental issues. Awareness and guidance materials should integrate existing ICAO environmental tools, guidelines, and manuals. Where possible they should encourage organizations to support higher-level ICAO environmental objectives, consider the collaborative nature of the aviation industry, and account for variance in types of organizations in the aviation sector and the level of EMS (or environmental program) maturity at the organization.

1. ***Disseminate Report Information.*** Within the first year of the CAEP/9 cycle, disseminate the CAEP/8 EMS report information to States, questionnaire respondents, and the public through various mechanisms (e.g., State letter, Assembly resolution language promoting EMS and/or principles, website, workshop, presentation).

2. ***Develop EMS Guidance***. Stand alone EMS guidance should be developed for the end of the CAEP/9 cycle. This should assist organizations to determine how EMS elements and principles can be used to enhance the way they manage environmental issues and provide practical guidance on how these EMS elements and principles can be implemented/integrated into existing management systems and business processes.

Chapter 10. Conclusion

In February 2007, the TG was assigned a project for the CAEP/8 work program to deliver a report providing information on the use of EMS and, as appropriate, make recommendations on how the committee could promote the use of EMS within the aviation system. As a result, the TG developed an industry questionnaire to learn more about the application and potential value of EMS to aviation organizations. A total of 233 responses from air navigation service providers, airlines, airports, and manufacturers formed the basis of this report and supported the development of recommendations.

Approximately 50 percent of questionnaire respondents (a total of 117) apply EMS standards or guidelines, with the majority having an ISO-14001 v2004 certified EMS in place. The remaining 116 respondents that have other environmental programs in place have many of the same principles and practices that are required as part of a formal EMS. For those organizations with an EMS, 82 percent have additional management systems in place—approximately 51 percent of these additional systems are integrated or coordinated with the organization's EMS. Over the past ten years, EMS implementation has been relatively consistent in the aviation industry. On average, respondents indicated that 6-12 months are needed to successfully develop and implement an EMS. Approximately 71 percent of organizations had assistance with EMS implementation from a consulting or contracting firm. Respondents indicated that the three most common benefits of EMS implementation are enhanced reputation or image, enhanced compliance and mitigation of risk, and environmental improvements.

Regardless of whether the respondent organization had an EMS in place, measuring environmental performance is important for ensuring compliance. On average, the majority of questionnaire respondents communicate environmental performance through a corporate social responsibility report or through their organization's website. Environmental areas of regulatory concern were primarily a focus of organizations regardless of whether or not they implemented an EMS. 79 respondent organizations without an EMS plan to implement one in the future. These organizations indicated that the most common reason for not implementing an EMS was unfamiliarity with EMS approaches. As a result, aviation industry specific EMS implementation guidance was requested by these organizations.

Recommendations were made on how ICAO-CAEP could promote the use of EMS within the aviation industry based on questionnaire results. The recommendations were to disseminate the CAEP/8 EMS report information to States, questionnaire respondents, and the public through various mechanisms, and consider development of EMS guidance. Any guidance should consider the collaborative nature of the aviation industry. This report is disseminated to States, questionnaire respondents, and the public in order to further increase awareness of EMS principles and best practices in the aviation sector.

References

International Civil Aviation Organization. *Assembly Resolutions in Force (as of 28 September 2007).* September 2007. http://www.icao.int/icaone1t/dcs/9902/9902_en.pdf

International Civil Aviation Organization. *Environmental Issues Related To Implementation of CNS/ATM System*. CNS/MET-ATM-IP/33. July 2003

International Civil Aviation Organization, Committee on Aviation Environmental Protection. *Environmental Management Systems*. CAEP/7-WP/54. February 2007

International Civil Aviation Organization. *ICAO Environmental Report 2007*. 2007. http://www.icao.int/env/pubs/Env_Report_07.pdf

International Civil Aviation Organization, Committee on Aviation Environmental Protection. *Update on Environmental Management System (EMS) Task*. CAEP8_WG2_LUPTG2_WP03. October 2007

International Organization for Standardization. *ISO 14001 Environmental management systems — Requirements with guidance for use,* November 2004 (2nd edition).

— — — — — — — —

Agenda Item 3: Review of market-based measures relating to aircraft engine emissions

3.1 REPORT OF THE MBMTF

3.1.1 In February 2007, CAEP/7 established the Market-based Measures Task Force (MBMTF) to undertake the work on the tasks related to market based measures, with five deliverables for consideration of the meeting:

a) M.01: Update the report on voluntary emissions trading for aviation;

b) M.02: Conduct a scoping study of issues related to linking open emission trading systems involving international aviation;

c) M.03: Conduct a scoping study on the application of emission trading and offsets for local air quality in aviation;

d) M.04: Examine the potential for emissions offset measures as a further means of mitigating the effects of aviation emissions on global climate change; and

e) M.05: Report to CAEP on agreed voluntary measures between Government and Industry to limit or reduce international aviation emissions.

3.1.2 Update the Report on Voluntary Emissions Trading for Aviation (Task M. 01)

3.1.2.1 The Report on Voluntary Emissions Trading for Aviation (VETS Report) published in 2007 has been updated to reflect changes to some ongoing schemes, the cessation of other schemes and the emergence of new voluntary emission trading regimes. While the updated report was largely completed by the last SG meeting in June 2009, a number of further updates have been made since that time. The original VETS Report contained information on voluntary offsetting schemes, which was subsequently moved to the report covering offset measures (M.04).

3.1.2.2 The report described the general nature of various types of voluntary emissions trading schemes, presented and summarized a number of practical experiences currently implemented throughout the world, and discussed the possible future development of such schemes involving aviation.

3.1.2.3 To avoid exclusion of possible future involvement by ICAO to set up any kind of voluntary emissions trading scheme, a revised text was proposed to replace the first two sentences of the updated report, paragraph 3.6 - Role of ICAO, with “ICAO is not presently directly involved in setting up voluntary emissions trading schemes. There are however roles that ICAO could pursue where appropriate.”

3.1.3 Discussion and Conclusions

3.1.3.1 The meeting expressed its appreciation of the efforts of MBMTF and noted the information provided in the updated VETS Report.

3.1.3.2 A member sought clarification on the reference in the Report to a working paper submitted to CAEP/7 regarding the ICAO *Guidance on use of emissions trading for aviation (Doc 9885)*, and its availability to the public. The Secretary suggested that instead of referring to the CAEP/7 working paper, reference be made to the ICAO Guidance itself and this was an acceptable way forward.

3.1.3.3 The member also sought clarification on the definition of "Annex I Parties or Countries" used in the report, and the VETS Report task lead responded that the task group did not develop a particular definition, but that the definition was derived from the overall MBMTF discussions and common to all MBMTF deliverables.

3.1.3.4 The meeting accepted the updated VETS Report, with the changes presented in paragraphs 3.1.2.3 and 3.1.3.2 above, and agreed that it should be published by ICAO.

3.1.4 **Recommendation**

3.1.4.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 3/1 – Publication of the updated report on voluntary emissions trading for aviation**
>
> That the updated report on voluntary emissions trading for aviation, as contained in Appendix A to the report on this agenda item, be published by ICAO.

3.1.5 **Conduct a scoping study of issues related to linking open emission trading systems involving international aviation (Task M. 02)**

3.1.5.1 The report on the scoping study of issues related to linking an emissions trading system involving international aviation with other greenhouse gas emissions trading systems was presented. The additional work on Section 5 (options for linking trading systems involving international aviation) and the Executive Summary, has been completed as requested at the last SG meeting. The report is organized according to the following key topics:

a) Linking arrangements – describing the benefits and risks of linking as well as the mechanics;

b) Possible future links;

c) Options for linking trading systems involving international aviation – exploring different types of linking arrangements and associated legal issues; and

d) Harmonization issues for bilateral and multilateral links – analysing key elements to be harmonized (e.g. coverage, sectors, gases, monitoring, verification, reporting).

3.1.6 **Discussion and Conclusions**

3.1.6.1 The meeting expressed its appreciation for the efforts of MBMTF and noted the information provided in the report on the scoping study of issues related to linking open emission trading systems involving international aviation.

3.1.6.2 A member expressed his view that, while this task was intended for a scoping study and not intended toward a specific linking system, equal levels of cap-setting would be a critical element for design and implementation of linking of systems and his concern was that an imbalance of cap-levels could cause adverse effect in CO_2 emissions reduction since it would restrain motivation of participants to reduce CO_2 emissions. The MBMTF Co-Rapporteur responded that a lot of elements should be addressed before the implementation of any linking of systems. In particular, the issue of “caps” would usually be the first item that would be further elaborated in a bilateral or multilateral discussion.

3.1.6.3 Another member pointed out that a definition of the term “carbon leakage,” frequently referred to in the report, should be included in the glossary. The Secretary suggested that, in coordination with MBMTF Co-Rapporteurs, the definition could be developed and included in the report prior to its publication.

3.1.6.4 Another member commented that as a technical committee, CAEP’s priority should be put on technical aspects rather than market-based measures. He also commented on the lack of data to conduct quantitative analyses on the efficiency and effectiveness of emissions trading systems, which should be undertaken in connection with the report. The MBMTF Co-Rapporteur responded that such issues could be the items to explore but beyond the scope of the report. The other Co-Rapporteur mentioned that in fact it would be difficult to undertake such studies as there were no schemes implemented for international aviation, and therefore such studies could only be based upon the data derived from the experiences in other sectors. The Chair deferred the consideration of the future work of MBMTF to Agenda item 5: Future Work.

3.1.6.5 The meeting noted the comments expressed, accepted the report, with the inclusion of the definition of “carbon leakage” in the glossary, and agreed that it should be published by ICAO.

3.1.7 **Recommendation**

3.1.7.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 3/2 – Publication of the Scoping Study of Issues Related to Linking Open Emissions Trading Systems Involving International Aviation**
>
> That the Scoping Study of Issues Related to Linking Open Emissions Trading Systems Involving International Aviation, as contained in Appendix B to the report on this agenda item, be published by ICAO.

3.1.8 Conduct a scoping study on the application of emission trading and offsets for local air quality in aviation (Task M. 03)

3.1.8.1 The report on the scoping study on the application of emission trading and offsets for local air quality in aviation was presented. It was agreed in the SG meeting in 2008 that text on offsets related to LAQ should be moved from M.04 to this task. Since the Salvador SG meeting, the Executive Summary has been completed, and previously separated sections have been combined to provide a checklist of the main airport-specific issues that need to be taken into account when considering emissions trading or offsetting for addressing an airport's local air quality situation. The report was organized according to the following key topics:

a) Definition of local air quality issues and mitigation measures in and surrounding airports;

b) Application of emissions trading and offsetting in local air quality management frameworks in other sectors;

c) Lessons learned from existing and historical local air quality management frameworks in other sectors; and

d) Outlining a framework for the application of emissions trading and offsetting to address local air quality in the airport context.

3.1.9 Discussion and Conclusions

3.1.9.1 The meeting expressed its appreciation for the efforts of MBMTF and noted the information provided in the report on the scoping study on the application of emission trading and offsets for local air quality in aviation.

3.1.9.2 A member congratulated the MBMTF on its efforts. While not anticipating major difficulties, she commented on the possibility of her State raising specific issues in the Council Session that could arise from a more thorough review of the document. Due to insufficient time, a review of the report was not possible prior to the meeting.

3.1.9.3 The Secretary pointed out that the report was the outcome of three-year thorough discussions and that no contentious issues were raised beforehand, and therefore she did not anticipate that major issues would be raised, however, it was unfortunate that the report was late and States did not have enough time to thoroughly review it.

3.1.9.4 The Secretary also clarified that she would, in coordination with MBMTF Co-Rapporteurs, make necessary editorial changes to reflect decisions made during CAEP/8 that would have implications on the way that some of the publications were referred to.

3.1.9.5 The meeting accepted the report and agreed that it should be published by ICAO.

3.1.10 **Recommendation**

3.1.10.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 3/3 – Publication of the Scoping Study on the Application of Emission Trading and Offsets for Local Air Quality in Aviation**
>
> That the Scoping Study on the Application of Emission Trading and Offsets for Local Air Quality in Aviation, as contained in Appendix C to the report on this agenda item, be published by ICAO.

3.1.11 **Examine the potential for emissions offset measures as a further means of mitigating the effects of aviation emissions on global climate change (Task M. 04)**

3.1.11.1 The report on offsetting emissions from the aviation sector was presented. Since the Salvador SG meeting, additional work has been completed on Chapter 3 (Definition of offsetting), Chapter 5 (Status and assessment of current aviation offsetting activities) and Chapter 6 (Opportunities for offsetting in regulatory and unregulated contexts). The report covered the following topics:

a) What is offsetting – defining the terms "offsetting" and "offset credits" and the use of offset credits in a regulatory context and an unregulated context;

b) Current status of the role of offsetting – exploring the role of offsetting in the context of cap-and-trade systems, baseline-and-credit systems and voluntary markets;

c) Current status of aviation offsetting activities – describing the type and volume of offsetting activity currently underway in the aviation sector; and

d) Analysis of offsetting for the aviation sector – assessing strengths, limitations and opportunities regarding offsetting as a further means of mitigating the effects of aviation emissions on global climate change.

3.1.11.2 The report concluded with a discussion of opportunities to use offsetting for the aviation sector in the future. At the passenger level, it is possible to draw on the current voluntary experience. However, there is also the possibility of using offsetting at a global sectoral level, either in a regulated emission trading system or through an emission charge. Offsetting can also be applied at an air carrier level rather than at the passenger level. These options offer some interesting possibilities for the future.

3.1.12 **Discussion and Conclusions**

3.1.12.1 The meeting expressed its appreciation for the efforts of the MBMTF and noted the information provided in the report on offsetting emissions from the aviation sector. The meeting accepted the report and agreed that it should be published by ICAO.

3.1.13 **Recommendation**

3.1.13.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 3/4 – Publication of the Report on Offsetting Emissions from the Aviation Sector**
>
> That the Report on Offsetting Emissions from the Aviation Sector, as contained in Appendix D to the report on this agenda item, be published by ICAO.

3.1.14 **Report to CAEP on agreed voluntary measures between Government and Industry to limit or reduce international aviation emissions (Task M. 05)**

3.1.14.1 It was agreed by the SG meeting in 2008 that the deliverable for this task to CAEP/8 would be a report on agreed voluntary measures between Government and Industry to limit or reduce international aviation emissions. Voluntary agreements are often considered as market-based measures as they are regarded as an alternative to regulation.

3.1.14.2 It was also agreed at the SG meeting that the compiling of information for the report on voluntary agreed measures would be conducted in cooperation with the Japanese Focal Point on Voluntary Measures (FPVM) and the ICAO Secretariat. A State letter on the collection of information on voluntary activity for greenhouse gas (GHG) reduction/mitigation in the aviation sector was sent to ICAO Member States in December 2009. It was expected that collecting and disseminating information on various voluntary measures, including agreed voluntary measures, to the aviation community would help and encourage the implementation of such measures.

3.1.14.3 Following the State Letter, the FPVM received 46 responses on voluntary measures, of which 3 initiatives undertaken were under a formal voluntary agreement between Government and Industry as follows:

a) Asia and Pacific Initiative to Reduce Emissions (ASPIRE), which involves airlines, air traffic control, airport authorities and governments in a voluntary agreed measure to work together to reduce aircraft fuel burn and CO_2 emissions through efficiency improvements on key Asia and Pacific routes;

b) Memorandum of Understanding between Transport Canada and the Air Transport Association of Canada to limit or reduce emissions of greenhouse gas (GHG) from aviation in Canada. The Agreement sets out a GHG emissions reduction goal for members of the Air Transport Association of Canada and covers both domestic and international air transport; and

c) A negotiated agreement in Romania involving airlines, air traffic control, government and manufacturers, which involves: Direct routes; Continuous Descent Approach at Henri Coanda International Airport, and Non-standard arrival trajectories (direct arrivals) at airports which provide approach services.

3.1.14.4 The FPVM welcomed additional submissions and updates on new and/or updated voluntary activities at any time, in order to ensure that a wide range of updated information could be disseminated. He proposed the update of ICAO's public website every 3 months, and the issuance of a State Letter every 3 years to request all States to submit information on new activities undertaken by entities in their States.

3.1.15 **Discussion and Conclusions**

3.1.15.1 Several members expressed their appreciation for the efforts made by the FPVM to collect relevant information, and noted the information provided as very useful.

3.1.15.2 The Secretary pointed out the late issue of the State Letter and the need for an earlier future action next time. She also suggested the notification to all CAEP members and observers on the update of information prior to every SG meeting using an e-alert.

3.1.15.3 The meeting endorsed the idea of making the collected information available through the ICAO public website, and of updating the ICAO public website every 3 months; the electronic notice before every SG meeting; and the issue of a State Letter every 3 years.

3.1.15.4 A member suggested the increased use of e-alerts in CAEP's work (i.e. when updates are made on the website).

3.1.16 **Recommendation**

3.1.16.1 In light of the foregoing discussion, the meeting developed the following recommendation:

> **Recommendation 3/5 – Publication of information on voluntary measures**
>
> That the information collected from Member States and international organizations on voluntary measures be made available through the ICAO public website and updated, as requested.

3.1.16.2 With regard to future work items of the MBMTF, given that this work would be dependent, *inter alia*, on the outcome of current international negotiations on the nature of a post-2012 climate change agreement and further discussions in ICAO, the MBMTF had not formulated recommendations for consideration of this meeting. MBMTF noted that if any direction would be made by the climate change negotiations or a newly established DGCA Climate Group, CAEP could initiate relevant work on market-based measures. The Chair deferred the further consideration of the future work of MBMTF to Agenda item 5: Future Work.

3.2 REPORT OF THE WG2 ON THE ROLE OF MARKET BASED MEASURES IN A MANAGEMENT FRAMEWORK FOR LOCAL EMISSIONS

3.2.1 Following the development of the ICAO *Guidance on Aircraft Emissions Charges related to Local Air Quality* (Doc 9884), CAEP/7 in February 2007 assigned WG2 with two tasks related to market-based measures to address aircraft emissions impacting LAQ as follows:

a) O.18: Role of market based measures in a management framework for local emissions - prepare a report that describes the various technical, operational, mitigation and market-based measures available to address aircraft emissions impacting LAQ, identifies the factors that might inform a decision to choose a particular measure or measures, and notes the potential interrelationships between the measures; and

b) O.19: Based on the information developed under O.18, develop draft text that could be used for the main page on the ICAO website that describes the available measures and further directs the reader to the relevant ICAO guidance documents that have been adopted on the subject.

3.2.2 The report on a management framework for local emissions identified and summarized the following ICAO documents, in addition to the LAQ charge guidance, as sources for guidance on emissions management measures that States would be assumed to have considered and analyzed for cost-effectiveness in the course of adopting an emissions charge:

a) Annex 16, Volume II - Aircraft Engine Emissions Standards;

b) ICAO Emissions Databank (Doc 9646);

c) Airport Air Quality Guidance Manual (Doc 9889);

d) Airport Planning Manual (Doc 9184);

e) Circular 303 - Operational Opportunities to Minimize Fuel Use and Reduce Emissions (or a manual replacing Circular 303); and

f) ICAO Environmental Report 2007 - A Cost Effectiveness Analysis of Local Air Quality Charges at Zurich and Stockholm Airports (pp. 84-91).

3.2.3 Based upon the report, the following new sentence on the ICAO public website (Environment - Aircraft Engine Emissions - The Use of Market-based Measures - As the 2nd sentence of the 7th paragraph) was proposed to note the existence of other publicly available ICAO guidance and documents, to which authorities might refer regarding the range of other measures that they would be assumed to have considered and evaluated for cost effectiveness:

> “That guidance assumes that States that have decided to adopt market based measures addressing local emissions have considered the range of available emissions reduction possibilities for airport sources, and conducted a cost effectiveness analysis. ICAO has

other guidance and documents to which States might refer in such an assessment of local air quality and identification of emissions reduction options.”.

3.2.4 The phrase “guidance and documents” in the proposed new sentence above would have a link to the proposed brief description of documents identified in the report as follows:

- *Airport Air Quality Guidance Manual*, Doc 9889 (AAQ Guidance) -- ICAO is in the process of developing guidance on practices for addressing local air quality in the vicinity of airports, The AAQ Guidance addresses operationally based inventory methods for aircraft emissions, establishing three levels of inventory methodology – Simple, Advanced and Sophisticated – for each source category. Use of the Advanced or Sophisticated methodology for inventories of aircraft engines would, in itself, produce more accurate estimates of aircraft engine emissions;

- The following ICAO/CAEP documents provide guidance and information on specific measures to address local emissions:

  - ICAO engine emissions standards, and data on certified engines as set forth in the ICAO Emissions Databank, Doc 9646 -- Authorities seeking to assess present and future air quality of airports for purposes of considering charges can take account of improvements stemming from such technological advances that may be foreseeable in their locations, for example through consultation of the Databank with reference to engine data relevant to known operator fleet renewal plans and/or fleet forecasts;

  - The ICAO *Airport Planning Manual,* in Chapter 3, outlines emissions control measures that airport operators, themselves or in cooperation with aircraft operators, can employ for aircraft, ground support vehicles and airport facilities;

  - ICAO Circular 303, *Operational Opportunities to Minimize Fuel Use and Reduce Emissions,* documents practices that all aviation stakeholders can consider to reduce fuel consumption and the resultant emissions. The Circular outlines principles of fuel savings by identifying operational opportunities and techniques for minimizing aircraft fuel use that in turn reduce the amount of emissions from these sources; and

  - *ICAO Environmental Report 2007*, *A Cost Effectiveness Analysis of Local Air Quality Charges at Zurich and Stockholm Airports*, pp. 84-91, sets forth the findings of a study that CAEP’s Forecasting and Economic Support Group (FESG) conducted to assess the cost effectiveness of existing NO_x charges at two airports. FESG could not make definitive inferences regarding the cost effectiveness of local air quality charges given the limitations on available data and time, but aspects of the FESG analysis in relation to both costs and environmental benefits may inform an authority’s assessment of the cost effectiveness of proposed charges versus other options under consideration for a particular airport. As the FESG study

> considered existing charges, a cost effectiveness analysis of prospective charges in the context of other available emissions management measures might entail consideration of additional factors.

3.2.5 The title of the documents would be linked to direct the user to the document, if available, on the website.

3.2.6 **Discussion and Conclusions**

3.2.6.1 The meeting expressed its appreciation for the efforts of WG2 and approved the report on a management framework for local emissions. The meeting also approved the proposed texts to be added by the Secretariat on the ICAO website.

— — — — — — — —

APPENDIX A

REPORT

ON

VOLUNTARY EMISSIONS TRADING FOR AVIATION

(VETS Report)

REVISED EDITION – 2009

International Civil Aviation Organization

Disclaimer

This report has been posted to the ICAO Website as a final draft. However, the contents shown are subject to change, pending editorial revision and further technical input. The Organization accepts no responsibility or liability, in whole or in part, as to currency, accuracy or quality of the information in the report or any consequence of its use.

TABLE OF CONTENTS

— — — — — — — —

CHAPTER 1 VOLUNTARY EMISSIONS TRADING CONCEPTS

1.1 Introduction

1.1.1 Discussions in ICAO CAEP

In evaluating alternative approaches to addressing aviation’s impact on the global climate, ICAO’s Committee on Aviation Environmental Protection (CAEP) concluded that, relative to other market-based measures, an emissions-trading system would be a cost-effective measure to limit or reduce CO_2 emitted by civil aviation in the long term, provided that the system is an open one across economic sectors.[1]

The 33rd ICAO Assembly (2001) endorsed the “development of an open emissions trading system for international aviation” and “requested the Council to develop as a matter of priority the guidelines for open emissions trading for international aviation, focusing on establishing the structural and legal basis for aviation's participation in an open trading system, and including key elements such as reporting, monitoring, and compliance, while providing flexibility to the maximum extent possible consistent with the UNFCCC process."

Subsequently, at its 35th Assembly (2004), ICAO endorsed the “further development of an open emissions trading system for international aviation” and requested the Council, in its further work on this subject, to focus on two approaches, namely to “support the development of a voluntary trading system that interested Contracting States and international organizations might propose” and to “provide guidance for use by Contracting States, as appropriate, to incorporate emissions from international aviation into Contracting States' emissions trading schemes consistent with the UNFCCC process”.

Under both approaches, the Council was instructed to ensure that the guidelines for an open emissions trading system address the structural and legal basis for aviation's participation in an open emissions trading system, including for example key elements such as reporting, monitoring and compliance.

The preliminary edition of this report was developed for CAEP by its Emissions Trading Task Force in response to the request to the Council to support the development of a voluntary trading system that interested Contracting States and international organizations might propose. This revised edition was prepared for CAEP by the Market-Based Measures Task Force which was established at the CAEP/7 meeting in February 2007.

1.1.2 Aviation’s role in the global economy

Aviation plays a vital role in facilitating economic growth, particularly in developing countries. It provides the only rapid worldwide transportation network, and transports about 2.2 billion passengers annually, as well as 35% of all international trade in goods (by value). According to industry sources[2], its global economic impact is estimated at US$ 3,560 billion (equivalent to 7.5% of world Gross Domestic Product (GDP) while generating a total of 32 million jobs globally.

The demand for air transport has increased steadily over the years. Passenger numbers have grown by 45% over the last decade and have more than doubled since the mid-1980s. Freight traffic has increased

[1] “Market-Based Measures:” Report from Working Group 5 to the fifth meeting of the Committee on Aviation Environmental Protection. CAEP/5-IP/22. 5/01/01.
[2] ATAG (2008) The Economic and Social Benefits of Air Transport 2008

even more rapidly, by over 80% on a tonne-kilometre performed basis over the last decade and almost three-fold since the mid-1980s.

1.1.3 Climate impact

Inclusion of aviation in an emissions trading system would require a decision regarding aviation emissions to be covered by the scheme.

The primary direct greenhouse gas emissions of aircraft are carbon dioxide (CO_2) and water vapour (H_2O). Other emissions are oxides of nitrogen (NO_x), particles containing sulphur oxides (SO_x) and soot. The total amount of aviation fuel burned, as well as the total emissions of carbon dioxide, NOx, and water vapour by aircraft, are well known relative to other parameters such as aerosols. These gases and particles alter the concentration of ozone (O_3) and methane (CH_4), may trigger formation of condensation trails (contrails), and may increase cirrus cloudiness – all of which may contribute to climate change.

According to estimates produced in the IPCC aviation report (1999), the overall radiative forcing from aircraft effects (excluding that from changes in cirrus clouds) in 1992 was a factor of 2.7 larger than the forcing by aircraft carbon dioxide alone.[3] The IPCC concluded that there were varying levels of scientific understanding (e.g. ranging from "very poor" in the case of cirrus to "good" for CO_2[4]) associated with these effects. Further research into such non-CO_2 effects is ongoing. The IPCC, in its fourth assessment report released in 2007, referred to more recent studies by Sausen et al. (2005) which estimated total aviation radiative forcing for the year 2000 of 47.8 mW/m2 compared with a radiative forcing for CO_2 alone of 25.3 mW/m2 giving a radiative forcing index of about 1.9. These radiative forcings represent the best estimate of the effects of aviation on climate for the reported year, i.e. 1992 and 2000. However, for aviation's past, present or future emissions, the radiative forcing index should not be used to derive relationships between emissions and marginal changes in climate, as the Global Warming Potential (GWP) is intended to do.

The Global Warming Potential (GWP) metric was developed by the IPCC, to compare the climate impacts of changes on emissions of long lived well mixed gases to that of CO_2 over a specific time horizon. It is used by the UNFCCC process in establishing emissions equivalencies for emissions reduction targets and activities. CO_2 impacts from aviation are the longest lived and most well defined and are readily defined in terms of GWP. Formulating GWPs from non-CO_2 effects from aviation has conceptual difficulties and the IPCC (1999) stated that such GWPs were not adequate to describe the climate impacts of aviation (see IPCC, 1999 Chapter 6 section 6.2.2).

For further information on emissions from the aviation sector please refer to the most current IPCC Assessment Report and the IPCC Special Report on Aviation and the Global Atmosphere.

1.1.4 International regulatory framework

The United Nations Framework Convention on Climate Change (UNFCCC), adopted at the Rio Earth Summit in 1992, aims to stabilize greenhouse gas concentrations in the global atmosphere. Under the UNFCCC, industrialized countries (named "Annex I Parties") shall adopt national policies and take corresponding measures on the mitigation of climate change by limiting its greenhouse gas emissions.

[3] The so-called RFI or radiative forcing index, is defined by the IPCC 1999 report as the sum of all the forcings divided by the CO_2 forcing (chapter 6 paragraph 6.2.3)

[4] For further details see the 1999 IPCC Special report on Aviation and the Global Atmosphere and the 2001 IPCC Third Assessment Report (TAR).

The UNFCCC is supplemented by the Kyoto Protocol of December 1997 which requires participating Annex I Parties to reduce their overall emissions of greenhouse gases by at least 5% below 1990 levels in the period 2008-2012, in accordance with the quantified emissions limitation/reduction commitments (QELRCs) as assigned to each of them individually in Annex B of the Protocol.

Parties' commitments under the Kyoto Protocol include emissions from domestic aviation, but emissions from international flights are not currently included. Article 2.2 of the Protocol states that "[T]he Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases (…) from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively".

Although non-Annex I Parties have no quantified obligations under the Kyoto Protocol, all Parties to the UNFCCC are called upon to take mitigation and adaptation measures, within the confines of their respective capabilities[5].

Voluntary participation in emissions trading schemes is equally relevant to Annex I and non-Annex I Parties and may be considered as a cost-effective complement to technology transfer and other mechanisms to reduce fuel consumption and increase resource efficiency.

1.2 Voluntary emissions trading explained

1.2.1 Rationale behind emissions trading

Emissions trading is a market-based policy tool that can be used to promote economic efficiency in achieving environmental goals. By harnessing market forces, emissions trading regimes can create incentives for economic agents to discover and implement cost-effective approaches to complying with environmental targets.

The basic argument for using emissions trading as an environmental policy tool relates to the potential costs saving a trading system can generate relative to a conventional command and control approach. In particular, when regulated entities are allowed to buy and sell emission instruments, market forces can create an incentive for firms with relatively low-cost emission reduction options to reduce their emissions by more than needed to satisfy their regulatory requirements.

These entities are then able to sell surplus emission instruments to other regulated firms that are faced with relatively high-cost emission control options. The opportunity to sell surplus emission instruments can create incentives for cost-effective compliance with environmental targets. As a result, incorporating an emissions trading system into an environmental policy can mean that the same level of environmental protection can be achieved at a lower overall cost. Care must be taken, however, that the savings in mitigation costs across all participants are large enough to more than offset the combined administrative and transactions costs.

1.2.2 Description of voluntary emissions trading

Various interpretations exist as to what is meant by voluntary emissions trading and specifically what is meant by the term 'voluntary'. According to the Organization for Economic Co-operation and Development (OECD), for example, there are many different examples of voluntary initiatives, ranging

[5] See Article 4 UNFCCC

from unilateral actions at the company level to negotiated agreements between governments and sectors [6]. The OECD also points to different ways in which voluntary programs can be combined with other measures such as taxes (most commonly involving some exemption), subsidies or standards. In practice, many voluntary agreements are in fact combined with some sort of incentive measure.

This report defines a voluntary trading scheme as any scheme in which participation is not made mandatory by a State. Schemes that involve some kind of government incentive for companies to participate therefore also fall under this definition.

For the purpose of this report, voluntary emissions trading for international aviation is considered to be one of the following:

1. a group of airlines decides to create its own ETS

For example, airline alliance partners set up an ETS among themselves. This would be a sectoral trading system that could be designed in a way that would allow participants to purchase offsets outside the scheme in order to keep costs down.

2. the airline sector creates a new ETS together with other sectors

For example, members of a national air transport association get together with the national electricity companies and agricultural sector to establish and participate in a national emissions trading scheme.

3. an airline/a group of airlines decides to unilaterally join an existing ETS
a) run by own government
b) run by other government(s)
c) run by a commercial entity

For example, as part of national efforts to drive technology efficiency and reduce emissions, a group of national airlines choose to participate in a trading scheme a) administered by its own government; or b) run in a neighboring State; or c) run by an independent trading platform.

Under these scenarios, the money paid by those buying allowances helps to finance the development and/or implementation of CO_2 control measures by others who are selling the allowances. In addition to these options, more direct mechanisms may also be considered, for example:

4. an airline/a group of airlines decides to compensate for carbon emissions by using an offset mechanism
a) run by the airline(s) itself (possibly as an option for passengers/customers)
b) run by an independent service provider.

While the preliminary edition of this report contained a description and discussion of carbon offset schemes, that material and further examination of offset schemes has been superseded by the report, *'Offsetting Emissions from the Aviation Sector'* prepared for CAEP by the Market-Based Measures Task Force.

[6] See OECD (2003) *Voluntary approaches for environmental policy- effectiveness, efficiency and usage in policy mixes*, and OECD (1999) *Voluntary Approaches for environment policy: an assessment*, OECD, Paris

1.2.3 Key considerations

A number of considerations are key in designing a workable and credible voluntary trading scheme. These include:

- ***Environmental results***—how stringent are the environmental targets, with what degree of certainty are these results achieved, how likely are entities to participate and how broad is the emissions coverage under the agreement, and what factors might undermine achieving the environmental results [7].
- ***Flexibility***—does the approach offer sufficient flexibility to ensure environmental benefits while allowing for economic growth within the sector and does it enable participants to take those actions that will most effectively reduce emissions and to encourage innovation in emissions reduction;
- ***Administrative & transaction costs***—how costly will requirements of the system be for the central administrative body and other entities (incl. the government) to administer and enforce, and how expensive will it be for entities to participate in the broad range of activities (such as monitoring and verification, reporting, and trading).
- ***Transparency***—how complex will the administration of the scheme be, how complex will it be for entities to participate in the scheme (incl. monitoring, verification, reporting and trading) and how transparent will the scheme be for third party stakeholders;
- ***Overall cost and cost-effectiveness***—does the option have adverse effects on the cost-effectiveness (i.e., the cost per tonne of CO_2 reduced) of control, or on overall control costs (i.e., the total costs of abatement plus purchase/sale of emission allowances and/or credits) for the aviation sector (domestic or international).
- ***Competitiveness***—how will the design of a trading scheme affect the competitive positions of participants and non-participants within the aviation sector, and between aviation and other transportation modes.
- ***Interactions with other mitigation options***—what types of issues arise regarding compatibility or conflicts with other policy instruments (standards, taxes, charges, other trading schemes, etc.) that exist or are being considered to address greenhouse gas emissions from aviation. Measures should not detract from other efforts to improve overall environmental performance.
- ***Political acceptability***—how will the trading scheme be viewed by the relevant stakeholders, including airlines and other industry actors that have an influence on aviation emissions but are not direct participants in the agreement (e.g. engine manufacturers, air traffic controllers), governmental and non-governmental bodies, etc.

[7] OECD assessment of voluntary initiatives in environmental policy concludes that their environmental effectiveness and economic efficiency is generally low compared to other approaches, but when measured against other criteria (so called 'soft' criteria) such as awareness raising they have been seen to have a very important role**.** See *supra* note 7

1.2.4 Opportunities for airlines created by voluntary emissions trading

There are a number of reasons why voluntary emissions trading schemes may provide a helpful option for addressing aviation emissions, particularly from international flights.

1.2.4.1 Flexibility

Voluntary trading schemes are not necessarily constrained by the framework of international agreements. This could allow early action under a voluntary framework while discussions on a possible mandatory approach are ongoing. It could also allow action that is broadly inclusive.

1.2.4.2 Cost containment

Successful voluntary measures can help to minimise costs, especially compared with the perceived cost of regulatory actions. As the action that needs to be taken to achieve a reduction target becomes more costly – approaching the cost of potential "command and control" regulations – the incentive to pursue voluntary trading diminishes. Therefore, successful voluntary measures should be cost-effective and have low administrative and transactions costs.

1.2.4.3 Competitiveness

Voluntary trading has potential to attract broad geographic participation by States and airlines. If the system attracts broad geographic participation, and since airlines are unlikely to join if they anticipate doing so will significantly hamper their ability to compete, competitive impacts are likely to be small.

1.2.4.4 Learning by doing

For companies not involved in mandatory trading schemes, a key benefit of voluntary trading might derive from "learning-by-doing" and from "institutional capacity building" within the airline sector. Starting out with a voluntary trading regime offers the important advantage of allowing participants the opportunity to develop skills and learn trading strategies that may be useful as emissions trading develops in the future. Voluntary emissions trading can be a step toward demonstrating to governments and the public that global warming concerns are being addressed responsibly.

The next chapter describes some examples of voluntary emissions trading schemes for greenhouse gases in which aviation participates or could participate.

CHAPTER 2 EXISTING & RECENT VOLUNTARY EMISSIONS TRADING SCHEMES

At the present time there are only a handful of examples around the world of voluntary emissions trading schemes for greenhouse gases. Only two of these trading schemes have included the activities of an airline operator. While the overall contribution of these schemes to global emissions reduction is small at present, the potential exists for this contribution to multiply over time if more schemes are developed.

This chapter summarises the key elements of the following voluntary schemes:

- United Kingdom Emissions Trading Scheme;
- Japan's Voluntary Emissions Trading Scheme (JVETS);
- Trial Voluntary Emissions Trading Scheme in Japan (2008-2012);
- Switzerland's Voluntary Emissions Trading Scheme
- Chicago Climate Exchange (with reference to the European Climate Exchange and the Montreal Climate Exchange);
- Asia Carbon Exchange; and
- Australian Climate Exchange.

2.1 UK Emissions Trading Scheme (UK ETS)

2.1.1 Overview

The UK ETS for greenhouse gases was launched by the Government in April 2002 as part of a wider range of measures in the UK designed to reduce greenhouse gas emissions under the UK Climate Change Programme. At the launch, it was claimed to be the world's first economy-wide greenhouse gas trading system.

A range of organisations, including British Airways as the only airline operator (domestic operations only), voluntarily undertook to reduce their emission of carbon dioxide equivalent (CO_2e) to below set targets. In return, these organisations (Direct Participants) received incentive payments totalling £215 million from the Government. Over the lifetime of the scheme (2002-2006), almost 12 million tonnes of CO_2e emissions releases were to have been avoided. The UK ETS ended in December 2006 with final reconciliation completed in March 2007.

The scheme was also open to the companies with Climate Change Agreements with the Government. These negotiated agreements set energy-related targets and companies meeting their targets received an 80% discount from the Climate Change Levy, a tax on the business use of energy. These companies could use the scheme either to buy allowances to meet their targets, or to sell any over-achievement of these targets. In addition, anyone could open an account on the registry to buy and sell allowances.

Transaction log data for the scheme indicated that there were over 9,000 transactions in the period from the commencement of the scheme to 31 March 2006[8]. Trades constituted almost 40 per cent of all transactions, with allocations, retirements and cancellations constituting around 40 per cent and the

[8] Appraisal of Years 1-4 of the UK Emissions Trading Scheme – a report by ENVIROS Consulting Limited for the UK Department for Environment, Food and Rural Affairs, December 2006.

remaining 20 per cent being intra-group transfers.

It was reported that over the lifetime of the scheme (2002 - 2006), Direct Participants achieved emissions reductions totalling 7.2 million tonnes of CO_2e.

2.1.2 **Participants and incentives**

Entry into the scheme was voluntary and open to all individuals or organisations in the UK. There are two principal types of participants - Direct Participants and Agreement Participants.

Direct Participants are organisations that agreed to take on voluntary targets for a five-year period, 2002-2006, in exchange for financial incentives provided by the Government. Thirty-three such organisations, including British Airways, committed to reduce their annual emissions against 1998-2000 levels by 3.96 million tonnes of CO_2e by the end of the scheme in 2006. In addition to fulfilling the total annual reduction target by 2006, Direct Participants had to comply with interim targets for years 2002-2005. Each year, the reduction target was increased by one-fifth of the overall (2006) target. As a result, the original commitment made by Direct Participants equated to delivering 11.88 (that is, (1/5+2/5+3/5+4/5+5/5) x 3.96) million tonnes of CO_2e worth of cumulative emissions releases avoided over the lifetime of the scheme.

As an incentive, the Direct Participants received a total of £215 million in payments from the Government over 5 years or approximately £43 million (£30 million after tax) per year. The level of incentive payment and the associated targets for each Direct Participant were set through a competitive bidding process.

Agreement Participants were those 6000 companies which already had emission or energy targets set through Climate Change Agreements with the Government. Companies meeting these targets received an 80 per cent discount from the Climate Change Levy, which is a tax on the business use of energy. These companies could use the scheme either to buy allowances to meet their targets, or to sell any over-achievement of these targets.

In addition to these participants, the UK ETS allowed other parties to participate in the scheme as traders without compliance commitments.

2.1.3 **Identifying emissions sources and calculating a Baseline**

The Baseline for each Direct Participant was calculated on the basis of historic emission levels and was generally the average annual emissions in the three years up to and including 2000.

The Baseline was made up of emissions from individual sources, which Direct Participants had to list by way of an approved protocol. The total emissions calculated using the approved protocol formed the Baseline expressed in tonnes of carbon dioxide equivalent (tCO_2e). Emissions included both direct emissions such as those from fossil fuel combustion or other industrial processes, and indirect emissions associated with energy use.

The Scheme made provision for adjustments to the Baseline to take account of changes in the structure or operations of a Direct Participant.

2.1.4 **Allocation of allowances**

For Direct Participants, a 'descending clock' auction was used to allocate the incentive money and the associated targets for emission reductions. Auction participants bid amounts of emission reductions in response to prices for tCO_2e announced by the Department for the Environment, Food & Rural Affairs (DEFRA), starting at a nominal £100. Companies submitted new bids in response to successively lower prices for tCO_2e until the total incentive payment implied was no more than the incentive budget of £215 million. This process gave a final price of £53.73 per tCO_2e reduction in 2006.

Because participants were required to make progressively larger reductions in each year of the Scheme, the 2006 reductions relative to the Baseline represented one-third of the cumulative total reductions from 2002-2006. The final price of £53.73 therefore corresponded to £17.79 per tCO_2e of cumulative reductions over the life of the Scheme, or £12.45 per reduction tCO_2e net of the maximum corporation tax due on the incentive payments.

The thirty-three Direct Participants pledged emissions reductions totalling 3.96 million tCO_2e in 2006, which is equivalent to 11.88 million tCO_2e of cumulative emissions releases avoided in total over the life of the Scheme. The 2006 target corresponded to a 13 per cent reduction from verified baseline emissions.

Direct Participants were subject to a 'cap and trade' emissions trading system. They were allocated allowances equal to the target for each year, provided they had been in compliance in the previous year. At the end of each compliance year, Direct Participants had to reconcile their verified emissions against their allowances and undertake any further trading necessary to meet their target.

Companies entering the Scheme through the Climate Change Agreements participated in a 'baseline and credit' trading system. They did not receive allowances up front. At the end of each year in which they had targets, they received allowances if they had beaten their target, or they were able to buy additional allowances if they had not beaten their target.

2.1.5 **Trading of allowances**

A computerised registry was the centralised means of managing all transactions. Anyone wanting to hold, buy or sell allowances or credits had to have an account in the registry. The registry recorded all allowance holdings and tracked allowances from their initial allocation through all transfers of ownership until final cancellation or retirement.

Anyone holding an account in the registry was allowed to buy and sell allowances. Participants in the scheme were able to trade directly between themselves or through third party brokers.

2.1.6 **Reporting, verification and compliance**

At the end of each compliance period (calendar years for Direct Participants and every two years for Agreement Participants), target holders reported their emissions over that period. All target holders had to ensure that they either held sufficient allowances to cover their verified emissions (for Direct Participants), or that they held sufficient allowances to cover any emissions or energy use in excess of their target (for Agreement Participants).

A three-month reconciliation period was allowed following each compliance period to enable participants to continue trading if required before a final deadline. After this, the Government checked the total holdings in each participant's account and all allowances needed to cover emissions over the preceding year were retired. Any allowances that remained could be banked for future use or sold.

Penalty provisions applied for non-compliance which were intended to be sufficiently strong to ensure the scheme operates effectively but not disproportionate for a voluntary scheme. For Direct Participants penalties could include financial penalties, non-payment of the financial incentive and a reduction in the number of allowances for the next compliance period. There was also the option for the Government to publicly list those Direct Participants who failed to hold sufficient allowances at the end of the reconciliation period. For Agreement Participants, the penalty was the removal of the 80 per cent discount on the Climate Change Levy.

2.1.7 **Results**

British Airways operated successfully within the UK ETS, meeting the reporting and verification requirements of the scheme, and keeping within its agreed emissions cap. Successful participation was greatly helped by agreeing a protocol with the UK government, which dealt with the key issues of monitoring and measuring emissions from mobile sources.

British Airways reported that participation in the UK ETS had brought valuable experience of operating with an emissions trading scheme. In addition to making cuts in CO_2 emissions and associated energy costs, the scheme has led to improvement in data accuracy and energy management information in a number of areas of operation.

The airline also cited a number of strategic benefits from participation in the scheme:

- Exposure to the concept within the business by taking into account the price of carbon in network planning decisions within its domestic network and integrating emissions trading into fuel hedging and financial management activities;

- Gaining experience of the processes and strategic implications, including the reporting of verifiable emissions data and credit trading; and

- Demonstration that emissions trading is a deliverable and practical policy tool for managing air transport emissions.

2.2 **Japan's Voluntary Emissions Trading Scheme (JVETS)**

2.2.1 **Overview**

In May 2005, the Ministry of the Environment launched the first phase of Japan's Voluntary Emissions Trading Scheme (JVETS). Under the scheme, the Ministry subsidised the installation of emissions reduction equipment for selected participants who made a commitment to specific reductions in their CO_2 emissions. The scheme also allowed these participants to trade CO_2 emission quotas to meet their reduction targets. The total emissions reductions for fiscal year (FY) 2006 were forecast to be almost 0.28 million tCO_2, while the total reduction over the officially-recognised service life of the subsidised equipment was calculated at about 3.8 million $tCO_{2.}$ The actual emissions reduction achieved for FY2006 was 0.38 million tCO_2.

A second phase of JVETS was implemented for FY2007.

The main purpose of the scheme was to achieve a cost-effective and substantial reduction in greenhouse gas emissions and to accumulate knowledge and experience relating to domestic CO_2 emissions trading.

A graphic illustration of the scheme is provided in Appendix A to this report.

2.2.2 **Participants and incentives – first phase**

An open invitation was made to private companies and other appropriate groups in Japan to participate in the JVETS. Of the 38 entities that applied, 31 companies and corporate groups were selected to participate based on the cost effectiveness of their emissions reduction proposals. In return for adopting specific emissions reduction targets, these 31 participants became eligible for Government subsidies for the installation of the emissions reduction equipment. Subsidies were only available for new facilities to improve energy efficiency or to promote renewable energy leading to greenhouse emissions reduction. The subsidies were capped at one third of the cost of installation involved and 200 million yen for each site. The total Government budget for the subsidies was about 3 billion yen (about US$27.2 million) for the first phase and 2.76 billion yen (about US$25.1 million) for the second phase.

The scheme provided for trading by the participants as required to meet their emissions reduction targets. There was also provision for 'trading participants' who were able to operate trading accounts but who were not eligible for subsidies or the allocation of allowances. Eight companies were selected as trading participants.

2.2.3 **Calculating baseline emissions and emission reductions – first phase**

The calculation of baseline emissions for each participant was based on their average annual CO_2 emissions between 2002 and 2004. For the 31 participants involved this equated to a total of over 1.3 million tCO_2. The total emissions reductions promised by the individual companies for FY2006 was almost 0.27 million tCO_2, or 21 per cent of their average annual CO_2 emissions in the base years. The total reduction over the officially recognised service life of the subsidised equipment was calculated at about 3.8 million $tCO_{2.}$

Participants received subsidies for new facilities and their installation during FY2005. The new facilities were to be set-up before the end of FY2005 (end March 2006) and the calculation of base year emissions also had to be completed by November 2005.

Base year emissions for all participants were verified by a Ministry accredited verification entity.

2.2.4 **Allocation of allowances – first phase**

The Ministry of the Environment allocated emissions quotas based on the results of the base years verification process. The allocations for each participant was the average emissions for the base years minus the estimated or pledged emission amount for FY2006.

2.2.5 **Trading allowances – first phase**

Throughout FY2006, participants implemented their CO_2 reduction projects using the newly installed equipment. Participants were able to trade their allowance throughout FY2006 which finished at the end of March 2007. At that time, actual greenhouse gas emissions were calculated and verified. Participants could trade allowances again if necessary before August 2007 when they were required to retire allowances in the registry.

2.2.6 Reporting, verification and compliance – first phase

At the completion of FY2006, participants had the period April to August 2007 to calculate their actual emissions for FY2006 and to submit the results to the third party entity for verification. The Ministry of the Environment funded the cost of verification.

Participants would have been non-compliant if they could not retire sufficient allowances corresponding to the actual amount of their emissions. In the case of non-compliance, the participant would have had to return the subsidy received to the Ministry for the Environment.

2.2.7 Results – first phase

The total emissions reductions for FY2006 was forecast to be 273,076 tCO_2, while the total reduction over the officially recognised service life of the subsidised equipment was calculated at about 3.8 million tCO_2.

All participants with commitments met their reduction targets by making the most of their emissions reduction facilities, as well as using the emissions trading system (when necessary), which resulted in a total annual emissions reduction of 377,056 tCO_2. This was equivalent to a 29 per cent reduction of the total base year emissions from participants' installations.

2.2.8 Second phase of JVETS

The Ministry of the Environment selected 61 companies and corporate groups as subsidised participants for the second period of JVETS. The total emissions reductions were estimated to be 217,167 tCO_2 for FY2007 while the total reduction over the officially recognised service life of the subsidised equipment were calculated as 2.8 million tCO_2. The operational period for FY2007 ended in March 2008 with final trading allowed up to August 2008.

All participants with commitments met their reduction targets by making the most of their emissions reduction facilities, as well as using the emissions trading system (when necessary), which resulted in a total annual emissions reduction of 280,192 tCO_2. This was equivalent to a 25 per cent reduction of the total base year emissions from participants' installations.

2.3 Trial Voluntary Emissions Trading Schemes in Japan (2008-2012)

2.3.1 Overview

In October 2008, the Japanese government announced the trial of a new emissions trading scheme to apply for FY2008 to FY2012, with fiscal years ending 31 March. Participation in the trial is voluntary. Companies that volunteer to participate in the scheme must set themselves CO_2 emission reduction targets for their business operations in Japan for every financial year during the 5-year period. Targets are submitted by each company for approval by the Japanese government. Companies that manage to achieve their CO_2 emission reduction targets and exceed them can trade credits with other companies in the scheme that have not managed to meet their own targets. Companies will not be penalised if they do not meet their targets. Participants were able to begin buying and selling each other's emissions as soon as the government had approved their targets.

2.3.2 **Participants**

When launching the scheme, the government set a notional target of 1,000 companies to volunteer as participants by the deadline of 12 December 2008. By the time the deadline was reached, over 500 companies had signed up to participate in the scheme. Participants included the largest power companies, chemical manufacturers and oil producers.

A large number of iron and steel manufacturers intended to join as one collective entity in the trial, aiming to cut emissions by 9 per cent below 1990 levels over the period of the trial. The Automobile Manufacturers Association set a target of 22 per cent below 1990 levels. All Nippon Airways (ANA) and the JAL Group are voluntarily participating in the scheme.

2.3.3 **Airline participation**

ANA has committed to an average 200,000 tonne reduction in annual CO_2 emissions from FY2008 to FY2011, compared with FY2006.

During the period of the scheme, the JAL Group has set itself, for each fiscal year, a target for cutting CO_2 emissions per available seat kilometre (ASK) of its Japan domestic fleet, when compared to 1990 levels. This includes all domestic operations by JAL and JAL Group airline subsidiaries HAC, J-AIR, JAC, JEX, JTA and RAC.

The JAL Group is targeting a 16 per cent cut in CO_2 emissions per ASK of its domestic fleet each year up until FY2012.

2.3.4 **Results**

As at October 2009, the scheme was still in its early stages of implementation and results were not yet available.

2.4 **Switzerland's Voluntary Emissions Trading Scheme**

2.4.1 **Overview**

The Swiss emissions trading scheme took effect on 1 January 2008. The scheme provides an opportunity for companies, especially those industries with substantial CO_2 emissions from use of heating fuels, to obtain exemptions from the CO_2 tax on heating fuels which has been levied since 1 January 2008 under the Federal Act on the Reduction of CO_2 Emissions (CO_2 Act). The CO_2 tax is an incentive tax aimed at promoting an economical use of heating fuels. Companies can be exempted from the CO_2 tax if they commit to restricting their CO_2 emissions.

The scheme is linked to pre-2008 voluntary agreements to reduce emissions. Companies covered by voluntary agreements can convert these agreements into legally binding CO_2 emissions targets, allowing them to participate in emissions trading and be exempted from the CO_2 tax.

2.4.2 Participants and incentives

The scheme primarily concerns companies that assume a legally binding commitment to reduce their energy-related CO_2 emissions and thus accept a target for 2008-2012. In return, these companies are exempted from the CO_2 tax. Each company, which has been exempted of the CO_2 tax by an official decision, receives emission allowances corresponding exactly to its reduction target. Small companies, for which no reduction target has been stipulated but which have set a specific target value for their emissions or a plan of actions, do not receive any emission allowances. However, they can buy emission credits to fulfill their commitment.

2.4.3 Calculating baseline emissions and emissions reductions

The Energy Agency for the Economy (EnAW) is mandated by the Swiss confederation to identify CO_2 emission reduction and energy efficiency potentials in trade, industry and service companies. In collaboration between the company and the EnAW, an action plan is developed and a reduction target is defined. These are audited by the Federal Office of the Environment (FOEN) and the Swiss Federal Office of Energy (SFOE) to become legally binding commitments that grant exemption from the CO_2 tax. Reduction targets in absolute terms are calculated using a bottom-up approach. A company's potential to reduce emissions, from a technical and economic viewpoint, is assessed on the basis of projected production and emissions, taking into account any CO_2 reduction measures already implemented. A simplified approach is used for small companies.

2.4.4 Allocation of allowances

Emissions allowances are allocated to the companies free of charge, in accordance with the targets negotiated for 2008-2012. Each year the FOEN adapts the CO_2 targets to the changed production growth. The last time this will be done is 2010.
Businesses that obtain an exemption from the CO_2 tax must open an account in the National Emissions Trading Registry (Registry) and this account is credited with emissions allowances corresponding to the company's emissions cap for that year.

2.4.5 Trading of allowances

Starting in 2008, emissions allowances equivalent to the amount of CO_2 emitted have to be surrendered each year. Allowances not required for compliance can be sold to other companies or carried over to the post-2012 commitment period. To cover excess emissions, allowances have to be purchased on the domestic or international markets and/or earned through emissions reduction projects abroad. The acquisition of allowances on the international market is limited to 8% of the targeted emissions reduction to ensure that a substantial part of the target is achieved domestically.

2.4.6 Reporting verification and compliance

Companies must annually surrender emissions allowances up to the amount they effectively emitted the preceding year. The companies do this themselves, surrendering the credits necessary to cover the emissions reported in the monitoring system of the EnAW. The emission credits are transferred from the holding account to the surrendering account within the Registry. The FOEN uses this account to check whether the company has surrendered sufficient emissions credits. In the case of non-compliance, the company has to pay the CO_2 tax plus any interest retroactively for the entire period since it was granted exemption.

2.4.7 Results

The numbers from the first year (of the commitment period) prove that companies took seriously their commitments and invested in early emission reductions.[9]

2.4.8 Future prospects

Within the CO_2 Act of May 2000, the federal council is obliged to propose further reduction targets for the time after 2012. Following public consultation, the federal council put forward a climate policy proposal for parliament. Main points were the continuation of CO_2 tax on heating fuels and the further development of the national emissions trading scheme with a view to linking it to the EU scheme. The proposal also mentioned the option to include international aviation in the emissions trading scheme. Progress on this matter can be followed on the website of Switzerland's Federal Department of Environment, Transport, Energy and Communications.[10]

2.5 Chicago Climate Exchange (CCX)

2.5.1 Overview

The Chicago Climate Exchange (CCX) is a voluntary, contractually binding, greenhouse gas emissions registry, reduction and trading system for emission sources, with offset projects worldwide. The development of the CCX was initiated through a feasibility study funded by a grant from the Chicago-based Joyce Foundation. A subsequent grant was given to initiate research on market implementation.

CCX is a self-regulatory, rules-based exchange designed and governed by CCX members. Members make a voluntary but legally binding commitment to reduce their emissions of greenhouse gases. By the end of Phase I (December 2006) all Members should have reduced direct emissions by four per cent below the average of their 1998-2001 baseline. Phase II, which extends the CCX reduction program through to 2010 requires all members to reduce greenhouse gas emissions by six per cent below the baseline.

Continuous electronic trading of greenhouse gas emission allowances and offsets began on 12 December 2003. CCX reduction commitments and trading apply for years 2003-2010. With a total emission baseline of over 365 million tCO_2e for 2006, the CCX program achieved a total emissions reduction of over 35 million tCO_2e by the end of Phase I in December 2006 which was substantially better than the target for Phase 1.

The CCX market price in June 2008 for CO_2 was about US$7 per tonne. The price has risen from around US$0.98 in December 2003.

[9] Further details are available on the website of Switzerland's Federal Department of Environment, Transport, Energy and Communications. Link: http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=de&msg-id=27786

[10] Link: http://www.bafu.admin.ch/dokumentation/medieninformation

2.5.2 **Participants and incentives**

Membership of the CCX is open to a wide range of participants. There are six categories of CCX membership, which together are referred to as CCX Registry Account Holders. The categories are:

a) Members are entities that have direct GHG emissions. Members make a legally binding commitment to the CCX Emission Reduction Schedule and are subject to annual verification by the Financial Industry Regulatory Authority (FINRA).

b) Associate Members are office-based businesses or institution with negligible direct GHG emissions who commit to report and fully offset 100 per cent of indirect emissions associated with energy purchases and business travel from year of entry through to 2010, and to have their emissions data verified by FINRA.

c) Offset Providers are owners of title to qualifying offset projects that sequester, destroy or reduce GHG emissions. Offset Providers register and sell offsets directly on the CCX.

d) Offset Aggregators are entities that serve as the administrative representative, on behalf of offset project owners, of multiple offset-generating projects. Offset projects involving less than 10,000 metric tons of CO_2e per year should be registered and sold through an Offset Aggregator.

e) Liquidity Providers are entities or individuals who trade on the CCX for purposes other than complying with the CCX Emissions Reduction Schedule such as market makers and proprietary trading groups.

f) Exchange Participants are entities or individuals who purchase Carbon Financial Instrument contracts and retire them to offset emissions associated with special events or other specified activities.

As at 12 October 2009 CCX membership totalled over 370. No airline operators or aircraft manufacturers were included in the membership. While Rolls-Royce is a member, this is in the context of its manufacturing activities and not in the context of aircraft engine emissions.

There are no Government funded incentives to participate in the CCX. The CCX promotes the benefits of membership as being:

1. Be prepared: mitigate financial, operational and reputational risks
2. Reduce emissions using the highest compliance standards with third party verification
3. Prove concrete action on climate change to shareholders, rating agencies, customers and citizens
4. Establish a cost-effective, turnkey emissions management system
5. Drive policy developments based on practical, hands-on experience
6. Gain leadership recognition for taking early, credible and binding action to address climate change
7. Establish early track record in reductions and experience with growing carbon and GHG markets

2.5.3 Identifying emissions sources, calculating baselines and setting emission reduction targets

Emissions of the following greenhouse gases from facilities owned by CCX members are included in the scheme as applicable: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons and sulphur hexafluoride.

Emissions of all non-CO_2 greenhouse gases are converted to metric tonnes CO_2 equivalent using the one hundred year Global Warming Potential (GWP) values established by the Intergovernmental Panel on Climate Change.

The unit of emissions measurement, reporting, price quotation and trading is metric tons of carbon dioxide equivalent or tCO_2e. Each CCX Carbon Financial Instrument represents one hundred tCO_2e.

CCX emitting Members make a voluntary but legally binding commitment to reduce direct emissions below an emissions baseline. An emissions baseline is calculated by taking the average of emissions inventories from a specific timeframe, or 'baseline period'. Baselines are adjusted to reflect acquisition or disposal of facilities.

Phase I Members: By the end of Phase I (December 2006) all Members should have reduced direct emissions by 4 per cent below a baseline period of 1998-2001. Members that participate in Phase II will reduce emissions by an additional 2 per cent below baseline by 2010 to achieve the Phase II reduction target of 6 per cent below baseline. CCX Members were issued greenhouse gas emission allowances at the inception of the program for the four-year period (2003-2006) in an amount reflecting the CCX emission reduction schedule below:

Phase I	**CCX Emission Reduction Target**
2003	1 per cent below Member's baseline
2004	2 per cent below Member's baseline
2005	3 per cent below Member's baseline
2006	4 per cent below Member's baseline
Phase II	**CCX Emission Reduction Target**
2007	4.25 per cent below Member's baseline
2008	4.5 per cent below Member's baseline
2009	5 per cent below Members baseline
2010	6 per cent below Members baseline

Phase II Member joining in 2006: New Phase II Members' emission baseline is the annual average of emissions from facilities included in the baseline period 1998-2001. If data is insufficient, new Phase II Members may use a year 2000 baseline. The Phase II reduction target is 6 per cent below baseline by 2010. CCX Phase II Members will be issued greenhouse gas emission allowances in an amount reflecting the CCX emission reduction schedule below:

Phase II	**CCX Emission Reduction Target**
2007	1.5 per cent below Member's baseline
2008	3.0 per cent below Member's baseline
2009	4.5 per cent below Member's baseline
2010	6 per cent below Member's baseline

2.5.4 **Emission offsets**

Emissions offsets are issued to owners or aggregators of eligible offset projects that sequester, destroy or displace greenhouse gases. Offsets are issued after mitigation occurs and required verification documentation is presented to the CCX. Project eligibility, project baselines, quantification, and monitoring and verification protocols are specified in the CCX Rulebook.

Eligible offset projects include but are not limited to the following types of projects (for which CCX has developed standardised rules for issuing CFI contracts):

- Agricultural methane;
- Coal mine methane;
- Landfill methane;
- Agricultural soil carbon;
- Rangeland soil carbon management;
- Forestry;
- Renewable energy; and
- Ozone depleting substance destruction.

Other projects to be approved on a project-by-project basis, may include:

- Energy efficiency and fuel switching; and
- Clean Development Mechanism (CDM) eligible projects.

2.5.5 **Allocation of allowances and offsets**

The tradable Carbon Financial Instruments employed in CCX are Exchange Allowances (XA's) and Exchange Offsets (XO's). Exchange Allowances are issued to emitting Members in accordance with each Member's Emission Baseline and Emission Reduction Schedule, subject to provisions outlined in the CCX Rulebook. Exchange Offsets are generated by qualifying offset projects.

Each CCX Carbon Financial Instrument resides in the CCX Registry in a manner that designates the Instrument's annual vintage. Each Carbon Financial Instrument is recognized as equivalent when surrendered for compliance. Carbon Financial Instruments may be used for compliance in their designated vintage year or banked for use in later years, subject to provisions outlined in the CCX Rulebook. CCX Carbon Financial Instruments may not be used for compliance in years that precede the vintage of an Instrument.

2.5.6 **Trading of allowances and offsets**

The CCX Trading System has three component parts:

1. *The CCX Trading Platform* is an internet-accessible marketplace that is used to execute trades among CCX Registry Account Holders. The system utilizes SUN java technology to bring live and active content to a screen. The Platform features a price transparent marketplace that displays order size, market depth and a market ticker. The system supports both exchange-cleared trades which preserve anonymity, and bilateral trades that are established through private negotiations off-system.

2. *The Clearing and Settlement Platform* receives information daily from the CCX Trading Platform on all trade activity. It processes all transaction information, nets out positions, and produces payment instructions for settlement of trades. Daily statements are provided to members when trading occurs. All corresponding changes are automatically updated in a Registry Account Holders' holdings of Carbon Financial Instruments in the CCX Registry.

3. *The CCX Registry* is an electronic database that serves as the official holder of record and transfer mechanism for Carbon Financial Instruments owned by Registry Account Holders.

The three components are integrated to provide Registry Account Holders with real-time data to support trading, assist in managing member emissions baselines, reduction targets and compliance status.

2.5.7 Reporting, verification and compliance

CCX has contracted with the Financial Industry Regulatory Authority (FIRA), formerly the National Association of Security Dealers (NASD), to provide regulatory services. FIRA assists in the registration, market oversight, and compliance procedures for CCX members. FIRA independently verifies Member's Baseline and annual emissions reports for Phase 1 and Phase 2 program years for accuracy and completeness, and to ensure compliance with the CCX Emission Reduction Schedule. FIRA utilises its state-of-the-art market surveillance technologies to monitor CCX trading activity. To ensure environmental integrity, offset verification services are provided by CCX-approved verifiers and are required for all exchange offset projects. FIRA also reviews all verifiers' reports for offset projects.

Compliance with the CCX Emissions Reduction Schedule is enforced by the CCX Environmental Compliance Committee. Members whose emissions do not meet annual emission reduction targets must use banked allowances from previous years or purchase CFI contracts on the CCX Electronic Trading Platform to meet their compliance requirements.

2.5.8 Results

As of October 2009, results had been released for the emission reduction compliance periods up to 2007. The results can be viewed on the CCX website.[11]

2.6 European Climate Exchange (ECX)

2.6.1 Overview

The European Climate Exchange (ECX) is a marketplace for trading carbon dioxide emissions in Europe and internationally. ECX is a subsidiary of Climate Exchange plc (CLE) which also owns the CCX. ECX currently trades two types of carbon credits: EU allowances (EUAs) and Certified Emissions Reductions (CERs). Trading on the ECX began in April 2005 when futures contracts were launched for EUAs. Trading of options for EUAs was launched in October 2006. Futures and options on CERs were introduced in 2008.

[11] Link: http://www.chicagoclimatex.com/content.jsf?id=250

There is no information available at this time as to whether the ECX has the potential to also support a voluntary emissions trading scheme involving aviation, but given the link with the CCX, voluntary trading could be a matter that interested airlines or other parties could explore with the ECX. ECX daily prices per tonne of CO_2 have ranged from €20 or US$25 (April 2005) to €30 or US$37 (April 2006). The ECX market price in April 2009 for CO_2 was about €12 or US$16 per tonne (for settlement in December 2009).

2.7 Montreal Climate Exchange (MCeX)

2.7.1 Overview

The Montreal Climate Exchange (MCeX) was established in July 2006 as a partnership arrangement between the Montreal Exchange (MX) and the Chicago Climate Exchange (CCX). It is intended to accelerate the development of a structured environmental market in Canada. The MX brings to the new climate exchange its expertise in leading-edge trading systems, clearing, market regulation and financial risk management. The CCX contribution is its extensive experience in operating climate exchanges in North America and Europe.

The mission of the MCeX is to offer price transparency, environmental integrity, low cost, wide access and reliability to those sectors of the Canadian economy involved in air quality and climate change concerns. The MCeX commenced its carbon trading activities in May 2008. Companies that earn greenhouse gas credits through environmental programs can use the new market to sell them to carbon-emitting firms.

2.8 Asia Carbon Exchange (ACX-Change)

2.8.1 Overview

The Asia Carbon Exchange (ACX-Change) was soft launched in May 2005 and became fully operational in November 2005. It is a fully owned subsidiary of the Asia Carbon Group, which is headquartered in Singapore. The ACX-Change is focussed both on the compliance market as well as on the voluntary carbon market (VERs). It is the world's first CDM focussed – auction based exchange. It claims to be uniquely positioned as a global platform for sellers and buyers of Certified Emission Reductions (CERs), having a presence globally. It gives sellers of CERs an exposure to a large number of potential buyers while giving buyers a broad range of CER sources with varied risk/benefit profiles to choose.

2.9 Australian Climate Exchange (ACX)

2.9.1 Overview

The Australian Climate Exchange (ACX), the first emissions trading platform in Australia, was created in 2007 to respond to growing demand for voluntary carbon offset products and is essentially a marketplace for buying and selling emissions commodities. The platform provides suppliers and purchasers of emissions offsets real time access to information concerning the state of the offset market and the prevailing market price for carbon. The exchange initially offered government accredited VERs and has since expanded, listing credits from multiple international verification standards.

To ensure the integrity of the trading system, ACX has established an offset registry that tracks the transfer of accredited offsets, both domestic and international, from creation through to the retirement of "spent" offsets, which have been used to reduce a quantity of GHG emissions. In conjunction with VER transfer protocols established between the ACX and various international registries, this is intended to ensure the correct transfer and maintenance of good title history, increased transparency and to provide an unbroken audit trail of offset custody eliminating double counting of offsets, thereby addressing a source of much of the speculation over the credibility of carbon offsetting to facilitate environmental benefits.

CHAPTER 3 FUTURE DEVELOPMENT OF VOLUNTARY EMISSIONS TRADING SCHEMES INVOLVING AVIATION

3.1 Introduction

As can be seen from Chapter 2 of this report, voluntary emissions trading schemes are becoming established in a number of countries – including two of the largest economies of the world, United States and Japan. Aviation participation has been confined so far to the UK Emissions Trading Scheme and the Trial Voluntary Emissions Trading Scheme in Japan (2008-2012). Even there, only domestic aviation services have been involved. However, there is scope for more airlines to become involved in some form of voluntary emissions trading. While there are a number of possible options for achieving this, as identified in Section 1.2.2, this chapter considers three broad ways in which this might be done:

- through participation in an existing voluntary emissions trading scheme;
- through the development of voluntary agreements as a precursor to an emissions trading system; and
- through the establishment of an aviation-only voluntary emissions trading scheme.

3.2 Participation in an existing voluntary emissions trading scheme

The extent of significant voluntary emissions trading schemes worldwide is generally as described in Chapter 2. On this measure, there would presently appear to be few opportunities available for airlines to participate in existing voluntary schemes. Furthermore, some of these schemes are either not open to new participants, are limited to certain countries, or do not appear to be readily adaptable for participation by airlines. These existing voluntary schemes may nevertheless be a first step towards voluntary emissions trading and might be expanded in the future.

Trial Voluntary Emissions Trading Scheme in Japan (2008 – 2012) is accessible to airline operators but only those operating domestic services in Japan. All Nippon Airways (ANA) and the JAL Group have chosen to participate in the scheme. Given the early stages of the operation of this scheme, its success has yet to be demonstrated.

Switzerland's Voluntary Emissions Trading Scheme would appear to be accessible to airline operators.

The Chicago Climate Exchange *(CCX)* and similar schemes would seem to have potential for providing a voluntary emissions trading facility for aviation. Even here there are significant implications for airlines that may wish to participate particularly in relation to the emissions reductions targets specified by the CCX.

It is likely that new voluntary emissions trading schemes for ground sources will be developed in the future. The adaptability of future schemes for aviation is a matter that cannot be assessed in advance. When considering the possible integration of aviation into such voluntary schemes, it could be expected that the aviation specific issues that arise would generally be similar to those applying to the integration of aviation into mandatory emissions trading schemes. Entities considering participation in a voluntary trading scheme should therefore refer to the *ICAO Guidance on the Use of Emissions Trading for Aviation* for a detailed discussion of relevant issues.

3.3 Development of voluntary agreements as a precursor to an emissions trading system

ICAO has created a Template for Voluntary Measures that may be used by airlines and/or governments as a starting point for the development of voluntary agreements to achieve emissions reductions. For example, such agreements might be based upon the establishment of a future fuel efficiency target for aircraft operators. To provide a basis for emissions trading such an agreement should include an enforceable commitment to achieve emissions reductions that are below an appropriate baseline.

To the extent that voluntary trading would be part of a voluntary agreement between government and industry partners, the ICAO Template for Voluntary Measures may be a useful reference document. It should however be noted that the ICAO Template was not designed with voluntary emissions trading schemes in mind and would have to be adapted for this purpose. The ICAO Template is available from ICAO at http://www.icao.int/icao/en/env/Caep_Template.pdf.

3.4 Establishment of a voluntary emissions trading scheme for aviation

One approach might involve the establishment by a group of airlines of a new voluntary emissions trading scheme for international aviation. This option would have more chance of being realised if it had the support of government(s). Given the greater worldwide focus by governments on solutions to climate change issues, the likelihood of such government support could be expected to increase over time.

This section will not attempt to address all of the issues involved in establishing a new emissions trading scheme but will only focus on aviation specific issues. In doing so, it is recognised that many of the aviation issues would be common to participation in either a voluntary scheme or a mandatory scheme. For other aviation issues, there would be specific differences between voluntary and mandatory schemes.

3.4.1 Commonalities between voluntary and mandatory emissions trading schemes

The *ICAO Guidance on the Use of Emissions Trading for Aviation* discusses the aviation specific issues relevant to the inclusion of international aviation in mandatory emissions trading scheme. This section draws on the guidance provided in that document to identify issues whose consideration in voluntary or mandatory schemes would be similar.

3.4.1.1 Accountable entities

Given that the voluntary emissions trading scheme considered in this section is assumed to be established by a group of airlines, then it follows that the accountable entities would be aircraft operators.

Accountable entities participating in a voluntary emissions trading scheme will be required, individually or jointly, to hold at the end of a trading period the necessary number of allowances (or credits) covering all relevant emissions, based on measured or modelled (calculated) emissions of their operations under the scope of the scheme.

3.4.1.2 Emission sources

The relevant sources of emissions that are to be controlled by the aircraft operator need to be defined. It is preferable that for international aviation the emission source be defined as all civil flights by the aircraft operator within the geographic scope of the scheme. Depending on the number and type of aircraft operators seeking to join the scheme, to lower the administrative burden it may be necessary to make exceptions by establishing an inclusion threshold based on aggregate air transport activity, aggregate emissions (measured in CO_2) or aircraft weight.

3.4.1.3 **Emissions species**

While participants are free to choose which emissions species to include in the scheme, there are several factors that could lead airlines to only include their CO_2 emissions. CO_2 emissions are the largest and most certain of the greenhouse gas emissions from the aviation sector. While non-CO_2 gases are potentially significant, there currently exists a high degree of scientific uncertainty associated with most of them. A CO_2 based scheme is most likely to be compatible with other trading schemes and so increase the potential for future trading between schemes. This would not preclude the inclusion of other aircraft emissions that contribute to climate change in the longer run.

3.4.1.4 **International and domestic emissions**

As States may take action to address international or domestic emissions in the future, any voluntary emissions trading scheme should take the precaution of distinguishing between international and domestic aviation emissions.

The IPCC definition of international and domestic emissions should be used for the purposes of accounting for greenhouse gas emissions from civil aviation. This approach is internationally accepted and will help ensure consistency between the various approaches of States and participants in voluntary schemes.

3.4.1.5 **Distribution of allowances**

Distribution of allowances could occur through grandfathering, auctioning or benchmarking. Grandfathering and auctioning do not raise specific issues that are significantly different for aviation than for other sectors. If benchmarking is being considered for distributing emissions allowances within the scheme, then recognition should be given to previous investment in new technology. Incentives should also be provided to operate the most emissions efficient aircraft in the most efficient way in the future.

3.4.1.6 **Monitoring, reporting and verification**

To ensure the integrity of the trading system clear procedures should be defined for monitoring, reporting and verification of emissions data. These procedures are primarily needed to help accountable entities identify and correct data and/or calculation errors. To avoid misrepresentation of actual emissions, verification procedures are important to ensure equitable treatment of all participants and to publicly demonstrate that obligations are fulfilled. Scheme participants would be responsible for the accurate and timely reporting of emissions data.

3.4.2 **Differences between voluntary and mandatory emissions trading schemes**

There are a number of issues that would clearly be different in a voluntary scheme compared with a mandatory scheme. One overarching consideration is whether the voluntary scheme would be accepted for trading by other emissions trading systems. Additional considerations are as follows:

3.4.2.1 **Participation**

By definition, there would be no compulsion to participate in a voluntary emissions trading scheme. In order to widen the scope of the scheme, increase the potential environmental benefits and the economic efficiency, and minimise competitive effects, airlines could consider joint participation, for example, as part of an airline association or airline alliance. New entrant airlines would not be obliged to participate in a voluntary scheme but should be able to join if they wished. Once emissions reductions commitments were made, there would need to be an enforceable obligation for participants to meet their targets.

3.4.2.2 **Incentives**

Governments may see benefits in providing financial support or incentives for the establishment or ongoing administration of a voluntary trading initiative. A voluntary scheme with incentives may encourage wider industry participation leading to additional environmental benefit. Incentives may also facilitate quicker implementation.

3.4.2.3 **Targets and timelines**

Participants could decide amongst themselves the stringency and the timing of the emissions reduction targets that would apply under the scheme. Targets would need to be set at a level that would give credibility to the scheme as an effective emissions reduction initiative. Conceivably, airline trade bodies could facilitate the negotiation and definition of relevant targets and timelines.

3.4.2.4 **Types of trading systems**

There is more flexibility in designing a voluntary trading scheme. Besides having the choice between adopting a capped system with allowances or some form of baseline and credit system, participants could opt for meeting their reduction targets separately and individually or for example jointly under a "bubble" agreement. The latter approach may combine a semi-open trading system with a clearinghouse function managed by a central administrator [12].

3.4.2.5 **Trading unit**

The participants in a voluntary scheme can decide amongst themselves the nature of the trading unit (or "allowance") to be used in the scheme. The allowance could represent an absolute amount of emissions (e.g. 1 tonne of CO_2) or, alternatively, an amount of emissions related to some measure of output (e.g. grams of CO_2 per ATK, RTK, ASK, or RSK).

To avoid the drawbacks of a 'closed' trading system, the scheme could be designed in a way that would allow participants to purchase offsets outside the scheme in order to keep costs down. However, selling scheme allowances into other trading schemes would depend on whether those other schemes accept these.

3.5 **How voluntary emissions trading for aviation could develop**

Looking at how voluntary emissions trading measures involving aviation have developed to date may provide some insight as to how new measures may develop into the future.

[12] The role of administrator could be filled for instance by a governmental agency, an industry body or an independent entity.

Voluntary agreements, depending on their nature, can be seen as a first step towards wider voluntary emissions trading although it is recognised that this is not a prerequisite. With airlines having experience with voluntary agreements, it might be easier for them to turn their attention to a voluntary trading scheme as a group in the future.

Government support would appear to be an important ingredient in a voluntary emissions trading scheme although not essential. With the back-up of well established voluntary agreements, airlines may find that government support for a trading scheme is more forthcoming.

The establishment of an airline-only emissions trading scheme would be within the capability of a group of airlines. The limitations of a closed trading system could be overcome by the ability to purchase offsets from other sectors. The level of sophistication and degree of integration with other sectors could then evolve over time.

3.6 **Role of ICAO**

ICAO is not presently directly involved in setting up voluntary emissions trading schemes. There are however roles that ICAO could pursue where appropriate. ICAO has already taken a first step by developing the ICAO Carbon Emissions Calculator. Other steps could include:

- Providing a forum to develop and review voluntary emissions trading schemes;
- Providing technical information to support such schemes;
- Encouraging consistency between such schemes;
- Encouraging the use and recognition of such schemes; and
- Facilitating or assisting in the verification of aviation emissions data.

3.7 **Further information**

Further information can be found in the *ICAO Guidance on the Use of Emissions Trading for Aviation* where the various design options are discussed in more depth and a number of recommendations are provided.

3.7.1 Finally, more general background information on emissions trading is available from the ICAO web site at (www.icao.int).

— — — — — — — —

GLOSSARY

The terms contained herein are intended to clarify concepts as used in this document.

Accountable entity
The entity in a cap and trade emissions trading system that is responsible for measuring and reporting actual emissions and for submitting sufficient allowances to cover those emissions.

Allocation
The initial distribution of allowances to accountable entities for a compliance period. This allocation could for example be based on historical emissions or a performance standard and level of production and could be made 'gratis' or through an auction process.

Allowance (emission allowance)
An allowance is a tradable emission permit that can be used for compliance purposes in a cap and trade system. Each allowance allows the holder to emit a specific quantity of a pollutant (e.g., one tonne of CO2) one time.

Annex B Parties or Countries
Group of industrialized countries and economies in transition listed in Annex B of the Kyoto Protocol that have commitments to limit or reduce their greenhouse gas emissions over the 2008-2012 period.

Annex I Parties or Countries
Group of industrialised countries and economies in transition included in Annex I to the United Nations Framework Convention on Climate Change (UNFCCC) that committed individually or jointly to returning to their 1990 levels of greenhouse gas emissions by the year 2000.

Auctioning
The distribution of allowance - either the initial distribution or from a set-aside, this is achieved through an auction in which system participants bid for the right to purchase allowances. Different auction models could be used. Auctions often complement other forms of allowance allocation.

Banking
A banking provision permits allowances issued for one compliance period to be saved for use during a subsequent compliance period.

Baseline
A reference level of emissions. A baseline can be used for example to calculate the total quantity of allowances to be distributed under a cap-and-trade scheme or the quantity of credits generated under a baseline-and-credit (emission intensity) system. A baseline also sets the level of emissions that would occur without policy intervention in an offset program.

Baseline and credit (emissions intensity) system
An emissions trading system that establishes an emissions performance standard and allows regulated participants to generate tradable credits (or "emission performance credits/allowances") by reducing their emissions intensity below that standard. Regulated participants that remain with an emissions intensity above the standard would need to submit credits to the regulating authority.

Benchmarking
A reference level, such as emission per unit of output, that can be part of the formula for the free allocation of allowances under a cap and trade system or that can define the target in an emission intensity system.

Bubble
A bubble is a regulatory concept whereby two or more emission sources are treated as if they were a single emission source.

Buyer
A legally recognised entity (individual, corporation, not-for-profit organisation or government) that acquires allowances or other compliance units from another legally recognised entity (the seller) through a purchase, lease, trade or other means of transfer.

Cap and trade emissions trading system
A Cap and Trade system allows for the trading of emission allowances that are limited or 'capped' in quantity by a regulatory authority. Before each compliance period, the regulatory authority distributes the allowances through a free allocation, sale, and/or auction. At the end of the compliance period each accountable entity must surrender sufficient allowances to cover its actual emissions during the period. The trading of allowances promotes cost-efficient emission reductions, as entities that can reduce emissions at lower cost have the incentive to pursue these emission reductions and to then sell their surplus allowances to entities that face higher emission reduction costs.

Carbon dioxide equivalent (CO_2e)
The unit of measurement that denotes the global warming potential (GWP) of a greenhouse gas. This metric enables the impact on the climate of different greenhouse gases to be easily compared.

Certified Emission Reductions (CERs)
A compliance unit under the Kyoto Protocol issued for emission reductions achieved from project activities in non-Annex I Parties that meet the requirements of the Clean Development Mechanism (CDM). One CER is equal to one metric tonne of CO_2 equivalent.

Cirrus cloud
A type of cloud composed of ice crystals and shaped like hair like filaments. May be partly induced by aviation.

Clean Development Mechanism (CDM)
A mechanism established by the Kyoto Protocol that enables emission reduction projects in non-Annex I Parties to earn CERs that can be sold to entities in Annex I Parties for compliance with their emissions limitation or reduction commitments under the Kyoto Protocol.

Climate change
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Contrails
The condensation trail left behind jet aircraft. Contrails only form when hot humid air from jet exhaust mixes with ambient air of low vapour pressure temperature.

Credit or offset credit
In this report the term ‘credit’ or ‘offset credit’ is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Distribution
The allocation of allowances among accountable entities in a cap and trade system.

Domestic aviation emissions
Emissions from civil domestic passenger and freight traffic (commercial, private, agriculture, etc.) that departs and arrives in the same country including take-offs and landings for these flight stages.

Domestic operations
Domestic flights and other aviation activities undertaken by an airline relating to those flights.

Emissions trading
Emissions trading is a market-based tool that provides entities the flexibility to select cost-effective solutions to achieve their environmental targets. With emissions trading, entities can meet these targets either by reducing their own emissions or by securing through the market compliance units that take account of emission reductions achieved elsewhere.

Fiscal year
A fiscal year (or financial year) is a 12 month period used for calculating (“yearly”) financial reports in business and other organisations. The specific 12 month period varies between countries.

Global Warming Potential (GWP)
Global Warming Potentials (GWP) are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme of CO_2 emitted over a period of time (100 years). For example, with carbon dioxide assigned a GWP of 1, methane has a GWP of 23.

Grandfathering
A method for the initial distribution of allowances to entities in an emission trading scheme that is based on historical data (e.g., gross emissions, entity/industry performance standard multiplied by production) and distributed free of charge.

Greenhouse gas
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent but very powerful greenhouse gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Greenhouse gas reduction or emissions reduction
A reduction in emissions intended to slow down the process of global warming and climate change. Greenhouse gas reductions are often measured in tonnes of carbon-dioxide-equivalent (CO_2e), which is calculated according to the GWP of a gas.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

Kyoto Protocol
An international agreement reached in Kyoto in 1997 that is linked to the UNFCCC and inscribes, among other things, the emission limitation and reduction commitments made by developed countries for the 2008-2012 First Commitment Period.

Non-Annex I Parties or Countries
Countries not included in Annex I of the United Nations Framework Convention on Climate Change (UNFCCC). Non-Annex I Parties do not have emissions limitation or reduction commitments under the Kyoto Protocol.

Offset or offset credit
In this report the term ‘offset’ or ‘offset credit’ is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Offsetting
In this report offsetting is the activity of “cancelling out” or “neutralising” emissions from a sector like aviation using offset credits – compensating emission reductions created in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

Open emissions trading
An emissions trading system where allowances or credits from outside the scheme can be used for achieving compliance with obligations under the scheme.

Retirement
The permanent surrender of offset credits (or allowances) to achieve compliance with a regulatory or voluntary obligation or a country’s international greenhouse gas commitment.

Seller
A legally recognised entity (individual, corporation, not-for-profit organisation, government, etc.) that transfers allowances or credits to another legally recognised entity via a sale, lease or trade in return for a monetary or other consideration.

Surrender of allowances/credits
The submission of emission allowances/credits by an accountable entity to fulfil its obligations under an emissions trading scheme.

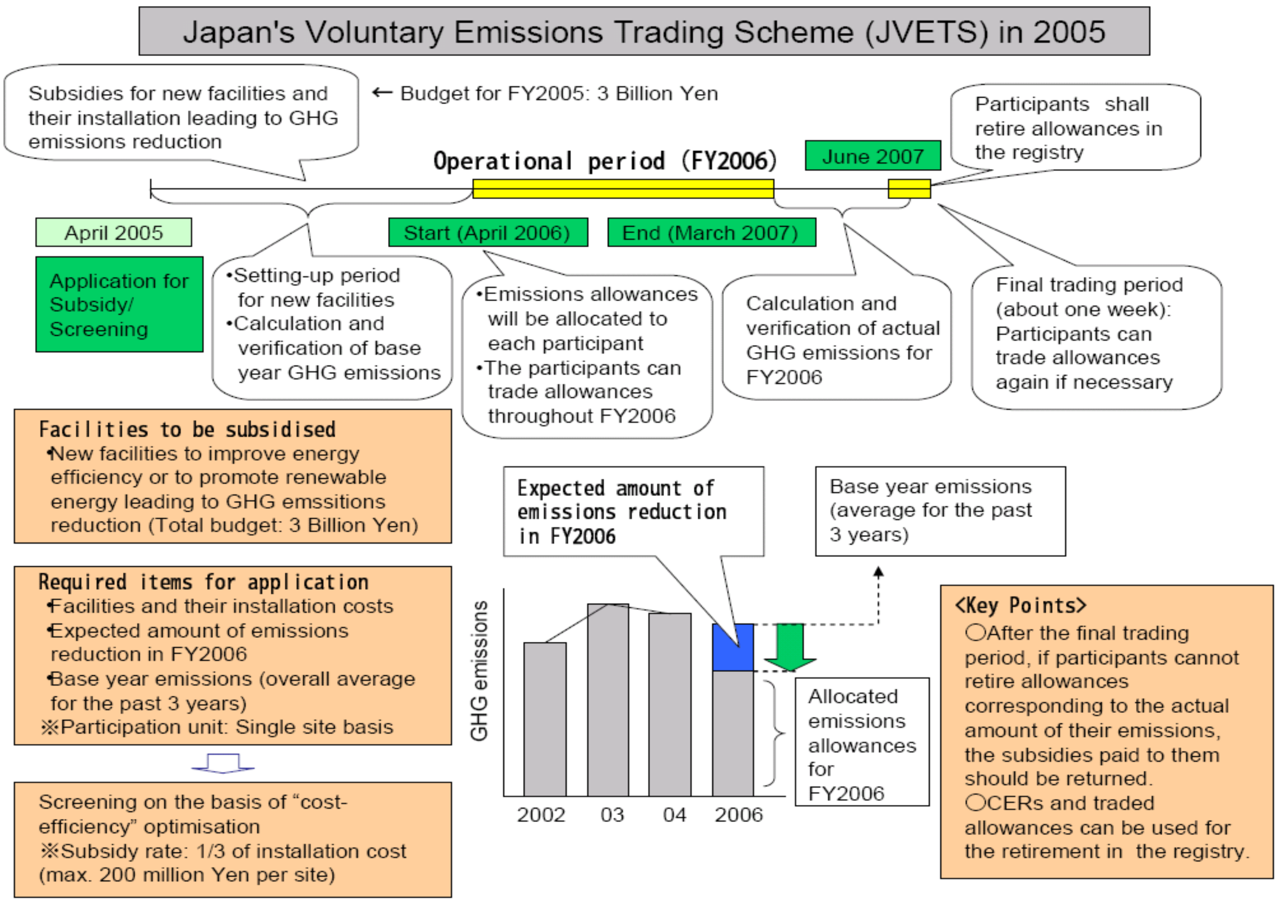
United Nations Framework Convention on Climate Change (UNFCCC)
The UN Convention on Climate Change has been ratified by 192 countries and it sets an overall framework for intergovernmental efforts to tackle the challenge of climate change. Under the Convention, governments share information on greenhouse gas emissions, national policies and best practices, commit to GHG limitation/reduction activities/targets, and provide financial and technical support for the adaptation and mitigation activities of other countries.

Verification
Verification provides independent assurance that the emissions quantification and reporting have been accurately completed. The 'level of assurance' provided depends on the system requirements. In most systems the verifiers must be accredited by a standard setting organization.

Voluntary action or commitment
An action or commitment undertaken by an entity that reduces greenhouse gas emissions in the absence of any requirements to undertake such reductions.

— — — — — — — —

Appendix A


Japan's Voluntary Emissions Trading Scheme (JVETS) in 2005
Subsidies for new facilities and their installation leading to GHG emissions reduction
← Budget for FY2005: 3 Billion Yen
Operational period (FY2006)
June 2007
Participants shall retire allowances in the registry
April 2005
Start (April 2006)
End (March 2007)
Application for Subsidy/ Screening
•Setting-up period for new facilities
•Calculation and verification of base year GHG emissions
•Emissions allowances will be allocated to each participant
•The participants can trade allowances throughout FY2006
Calculation and verification of actual GHG emissions for FY2006
Final trading period (about one week): Participants can trade allowances again if necessary
Facilities to be subsidised
•New facilities to improve energy efficiency or to promote renewable energy leading to GHG emssitions reduction (Total budget: 3 Billion Yen)
Required items for application
•Facilities and their installation costs
•Expected amount of emissions reduction in FY2006
•Base year emissions (overall average for the past 3 years)
※Participation unit: Single site basis
Screening on the basis of "cost-efficiency" optimisation
※Subsidy rate: 1/3 of installation cost (max. 200 million Yen per site)
Expected amount of emissions reduction in FY2006
Base year emissions (average for the past 3 years)
GHG emissions
2002
03
04
2006
Allocated emissions allowances for FY2006
<Key Points>
○After the final trading period, if participants cannot retire allowances corresponding to the actual amount of their emissions, the subsidies paid to them should be returned.
○CERs and traded allowances can be used for the retirement in the registry.

— — — — — — — —

APPENDIX B

Scoping Study of Issues Related to Linking 'Open' Emission Trading Systems Involving International Aviation

Table of Contents

1. EXECUTIVE SUMMARY

1.1 For international aviation, compliance with an ambitious target to reduce emissions from the sector may require the use of tradable compliance units from another sectoral, multi-sectoral or economy-wide national, regional or international emissions trading scheme. In addition, units from project-based or program-based mechanisms such as the Clean Development Mechanism could also be considered for use.

1.2 In this report it is the linking of schemes that will result in open emissions trading involving international aviation that is of interest. Although different definitions for "open emissions trading" can be found in the literature, its use here is aligned with the way ICAO has used the concept in the past. Thus a system is regarded as open when the international aviation sector has access to compliance units from outside the aviation sector. A closed emissions trading system would be an international aviation-only system where only units from the international civil aviation sector could be traded and used for compliance purposes. The latter is not part of the scope of this paper.

1.3 Schemes that include emissions from international aviation as well as other sectors could have unique aviation and non-aviation tradable units, and could restrict the type of tradable units that are accepted for achieving compliance by participants in the system. However, the key benefit of an 'open' system for participants in the international aviation sector comes from their ability to use non-aviation tradable units for compliance purposes. This is likely to reduce compliance costs for the sector.

1.4 The administrator of a trading system can establish a unilateral link with another system by agreeing to accept tradable units issued by the other system for compliance purposes. Alternatively, the administrators of two systems can establish a bilateral link if each agrees to accept tradable units issued by the other system for compliance purposes. With a bilateral link tradable units can be freely traded between the systems and are equally valid for compliance purposes in both systems.

1.5 When considering the creation of either a unilateral or bilateral link, the choice of the system(s) with which it might be possible to link will be assessed in terms of:

- the perceived quality of the tradable units of the target system;
- the ease of establishing a link with the target system; and
- the size of the target system relative to the projected demand for external tradable units by the international aviation sector.

1.6 The potential benefits of linking one or more systems involving international aviation emissions include:

- lower net cost of meeting emissions obligations in linked systems as a result of the flexibility to acquire and use for compliance purposes the lowest cost emission reduction measures across all participants;
- increased incentives for entities to find cost effective ways to reduce their emissions as the market for selling excess emission reductions grows;
- reduced price volatility of tradable units due to the creation of a larger, more liquid market for these units; and

- reduced competitiveness concerns and a reduced likelihood of carbon leakage due to the convergence of tradable unit prices in the linked systems.

1.7 The main risks associated with linking are as follows:

- higher prices for the tradable units in the net supplier system (with unilateral or bilateral linking);
- higher total emissions if differences in system design, including provisions related to monitoring, verification and reporting and the compliance penalties, result in the effective application of the least stringent requirements; and
- incentive to limit the requirement to achieve emission reductions (for example, make smaller reductions to the emissions cap over time) so that participants can benefit from exporting tradable units to the linked system.

1.8 Many of the risks noted above can be reduced by harmonizing the relevant provisions enough to make the linked systems "compatible".

2. INTRODUCTION

2.1 Background

2.1.1 During the 7th meeting of the Committee on Aviation Environmental Protection (CAEP) in February 2007, the *Guidance on Emissions Trading for Aviation* and the *Report on Voluntary Emissions Trading for Aviation* were finalized.[1] Both reports are available from the International Civil Aviation Organization (ICAO).[2] To further CAEP's work on emissions trading and other market-based measures, the Market-Based Measures Task Force (MBMTF) was created with a mandate of scoping out several issues related to the use of market-based measures to address air emissions from the aviation sector.

2.1.2 One of the work items identified for the MBMTF was to write "a scoping paper on issues related to linking 'open' emission trading systems involving international aviation". This document has been prepared in response to that request.

2.2 Context

2.2.1 The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) requires countries listed in Annex I of the Convention (largely developed countries) to reduce emissions of greenhouse gases.[3] The first compliance period of the Kyoto Protocol covers the period 2008 to 2012; its successor is currently under discussion.[4]

---

[1] *Guidance on Emissions Trading for Aviation* (CAEP-IP/20) and the *Report on Voluntary Emissions Trading for Aviation* (CAEP7-IP/19) were adopted by the CAEP at its 7th meeting in February 2007. It should be noted that there was an EU reservation to the adoption of the *Guidance* document.

[2] The *Guidance on Emissions Trading for Aviation* (Doc 9885); *Report on Voluntary Emissions Trading for Aviation* (http://www.icao.int/icao/en/env/vets_report.pdf)

[3] Throughout this scoping paper, reference to developed countries implies Annex I countries; reference to developing countries implies non-Annex I countries.

[4] A brief description of the Kyoto Protocol and Annex I countries is available in the Glossary.

2.2.2 The Kyoto Protocol treats emissions from the international and domestic aviation sector differently. Domestic aviation emissions are included in national targets.[5] Emissions from domestic aviation include emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-offs and landings for these flight stages.[6] On the other hand, although international aviation emissions are not included in the targets listed in Annex B of the Kyoto Protocol, the Protocol assigns the UNFCCC Annex 1 Parties, working through ICAO, the responsibility of pursuing the limitation or reduction of greenhouse gas emissions from aviation bunker fuels (see Article 2.2 of the Protocol).[7] Emissions from international aviation include emissions from flights that depart in one country and arrive in a different country, including take-offs and landings for each flight stage.

2.2.3 Aviation emissions contribute to the radiative forcing (RF) of climate.[8] The primary direct greenhouse gas emissions of aircraft are carbon dioxide (CO_2) and water vapour (H_2O). Other emissions are oxides of nitrogen (NO_x), particles containing sulphur oxides (SO_x) and soot. These gases and particles alter the concentration of ozone (O_3) and methane (CH_4) in the atmosphere, can trigger the formation of condensation trails (contrails), and may increase cirrus cloudiness – all of which contribute to climate change.

2.2.4 The Intergovernmental Panel on Climate Change (IPCC) *Fourth Assessment Report* (AR4) estimated aviation's contribution to global carbon dioxide emissions in 2005 to be 2%, and its contribution to total anthropogenic radiative forcing to be 3% [9]. This 2005 figure is based on aircraft operations data for 2000. In a more recent scientific study that included new operational data for the period 2000–2005, total aviation radiative forcing in 2005 (excluding cirrus) was found to be 3.5% of total anthropogenic forcing (or 4.9% if estimates for aviation-induced cirrus are included).[10]

2.2.5 Even though the aviation sector continues to improve the relative efficiency of its operations through fleet renewal, improved scheduling/routing, fuel efficiency and other technical advances, operational adjustments alone will not fully counterbalance CO_2 emission increases that are expected to be in the range of approximately 3-4%[11] per year as the sector continues to grow. Other measures that would allow the sustainable growth of the sector and contribute to further mitigation of CO_2 emissions could be implemented.

2.2.6 The global warming impacts of CO_2 emissions are the same regardless of where the emissions occur. Thus reductions in CO_2 from the international aviation sector could be achieved or recognized through participation in a multi-sector emissions trading system or through offsetting –

---

[5] ICAO Environmental Report 2007, Montreal, Quebec, page 149 (available at www.icao.int).

[6] IPCC, 2006. *2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2: Energy*. Pages 3.57-3.58. (available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf)

[7] "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively." Kyoto Protocol, Article 2, paragraph 2.

[8] Radiative forcing components arise from: emissions of CO_2 (positive RF); emissions of NO_x (positive RF), including the sum of three components: production of tropospheric O_3 (positive RF), a longer-term reduction in ambient methane (CH_4) (negative RF), and a further longer-term decrease in O_3 (negative RF); emissions of H_2O (positive RF); formation of persistent linear contrails (positive RF); aircraft-induced cirrus cloudiness (potentially a positive RF); emission of sulphate particles (negative RF); and emission of soot particles. Source: Lee et al, *Atmospheric Environment*, April 2009.

[9] Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), 2007, WGIII Technical Summary, page 49. The Report is available at http://www.ipcc.ch/ipccreports/ar4-wg3.htm. A brief description of the Intergovernmental Panel on Climate Change is available in the Glossary.

[10] Lee et al, Atmospheric Environment, April 2009.

[11] Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), 2007, WGIII Technical Summary, page 49. The Report is available at *http://www.ipcc.ch/ipccreports/ar4-wg3.htm*.

the purchase and retirement of emission reduction allowances or credits from sources outside of the sector. Alternatively emissions trading systems could be linked to allow compliance units from other systems to be used to achieve the voluntary commitment or regulatory obligation.

2.2.7 A number of emissions trading systems for greenhouse gases are operational and some of these systems have already been linked. As more and more countries or regions are establishing emission trading systems, the interest in linking is growing. The establishment of the International Carbon Action Partnership (ICAP) as a forum for public authorities committed to mandatory cap and trade systems to generate a better understanding of good ETS design and to promote the development of systems that could be compatible for linking is a good indicator of this interest.

2.2.8 It is also important to note that beginning January 1, 2012, CO_2 emissions from international aviation will be included in the European Union Emission Trading Scheme (EU ETS). Covered under the scheme will be all flights from, to and within the European Union performed with aircraft with MTOW above 5.700 kg. There will be a number of exclusions, including a *de minimis* rule that excludes flights performed by a commercial air transport operator operating less than 243 flights per period for three consecutive four-month periods, or operating flights with total annual emissions under 10,000 tonnes per year.[12]

2.3 Purpose

2.3.1 The purpose of this scoping paper is to review issues related to the linking of greenhouse gas emissions trading systems. Two systems are linked if entities can trade compliance units across scheme boundaries, with a participant in one system able to use a compliance unit issued by the administrator of the other system to achieve its voluntary commitment or regulatory obligation. More specifically, in this report it is the linking of schemes that will result in open emissions trading involving international aviation that is of interest. Although different definitions for "open emissions trading" can be found in the literature, the concept as used here is aligned with the way it has been used in recent ICAO publications. Thus a system is regarded as open when the international aviation sector has access to compliance units from outside the aviation sector; a closed emissions trading system would occur if compliance units could be traded within the aviation sector only.

2.3.2 It is noted that the definitions used in ICAO's *Guidance on the Use of Emissions Trading for Aviation*[13] characterise "open" and "closed" with reference to whether or not the sector has access to allowances and credits from outside an aviation trading scheme. Earlier analysis of emissions trading by Working Group 5 and FESG during CAEP/5, describe an open system as one in which emissions from all aviation sources are treated identically to other emissions, with bilateral trading allowed between the aviation sector and other sectors.[14] [15] A closed system, on the other hand, was described as a system in which aviation emissions could only be traded within the

[12] Directive 2008/101/EC of the European Parliament and of the Council of 19 November 2008 amending Directive 2003/87/EC so as to include aviation activities in the scheme for greenhouse gas emission allowance trading within the Community – OJ 13.01.2009

[13] ICAO, 2008, Doc 9885 First Edition *Guidance on the Use of Emissions Trading for Aviation*

[14] ICAO, 2001, CAEP 5 WP16, Working Group 5 Report *Overview from Working Group 5 on Development of Market-based Measures to Limit or Reduce Emissions from Civil Aviation*

[15] ICAO, 2001, CAEP 5 WP24, FESG Report, *Economic Analysis of Potential Market-based Options for Reduction of CO2 Emissions from Aviation*

aviation sector with a fixed cap. The CAEP 5 conclusion was that "a closed emissions trading system does not show cost benefit results to justify further consideration".[16]

2.4 Scope and Structure

2.4.1 This paper is limited to considering and assessing emissions trading systems for greenhouse gases.[17] For aviation, only the CO_2 emissions are considered.[18] It would be more technically challenging to include the non-CO_2 effects of aviation such as NOx, contrails and water vapour in a trading system as such a system would need to take into consideration the scientific evidence related to these effects, their duration, and their variability over time and location. So far such a scheme has not been implemented anywhere.[19]

2.4.2 The trading activities described in this paper focus on trading at the source, facility, project or corporate level. Trading between countries of assigned amount units (AAUs), or other credits used by countries for the purposes of balancing national accounts to maintain compliance with international commitments, is considered only in the context of describing direct or indirect links between emission trading systems.

2.4.3 Arrangements for linking emissions trading systems are reviewed in Chapter 3. The experience with linking and the prospects for future links are discussed in Chapter 4. Options for linking trading systems involving international aviation with other emissions trading systems are considered in Chapter 5. Issues that could affect the compatibility of a trading system for international aviation with other emissions trading systems are analyzed in Chapter 6.

3. EMISSIONS TRADING SYSTEMS

3.1 Types of Trading Systems and Tradable Units

3.1.1 An emissions trading system requires specified entities to monitor or calculate their emissions. In a scheme where total emissions are capped and tradable emission units are allocated either without cost or through sale/auction – a **'cap and trade system'**, at the end of the compliance period (which in current systems vary from one to five year(s))[20], each entity must provide the regulatory authority with tradable units equal to its actual emissions. In schemes where specified entities have a target based on emissions per unit of production – an **'emissions intensity system'** (or 'baseline-and-credit' system'), at the end of each compliance period each entity must submit tradable units to cover any excess of actual emissions over target emissions or will receive credits from the regulatory authority to the extent its actual emissions are less than its target emissions.

---

[16] CAEP, 2001, *Report of the Fifth Meeting of the Committee on Aviation Environmental Protection (CAEP)*

[17] The six gases covered by the Kyoto Protocol are Carbon dioxide (CO_2), Methane (CH_4), Nitrous oxide (N_2O), Hydrofluorocarbons (HFCs), Perfluorocarbons (PFCs) and Sulphur hexafluoride (SF_6).

[18] As indicated in the 2006 *IPCC Guidelines for National Greenhouse Gas Inventories,* aircraft engine emissions are roughly composed of about 70 percent CO_2, a little less than 30 percent H_2O, and less than 1 percent each of NO_x, CO, SO*x*, NMVOC, particulates, and other trace components including hazardous air pollutants. Little or no N_2O emissions occur from modern gas turbines (IPCC, 1999). Methane (CH_4) may be emitted by gas turbines during idle and by older technology engines, but recent data suggest that little or no CH_4 is emitted by modern engines. Emissions also depend on the number and type of aircraft operations; the types and efficiency of the aircraft engines; the fuel used; the length of flight; the power setting; the time spent at each stage of flight; and, to a lesser degree, the altitude at which exhaust gases are emitted. For more information, see: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf

[19] It is also noted that CO_2 emissions have impacts that extend beyond climate change/global warming. For more information, see: http://www.iata.org/whatwedo/environment/climate_change.htm

[20] Note for example that the EU ETS has multi-year trading periods though compliance is annual.

3.1.2 The types of tradable units that will be accepted for compliance purposes (each representing the equivalent of one tonne of carbon dioxide emissions), and quantitative limits on their use (if any), are identified in advance by the responsible authorities.

3.1.3 In Annex B of the Kyoto Protocol the binding greenhouse gas emissions targets taken on by industrialized countries are listed. The tradable Kyoto units that an Annex I Party of the UNFCCC can surrender to meet its Kyoto Protocol obligations are:

- **Assigned Amount Units** (AAUs) – units equal to the commitment of Annex B Parties (emission-capped countries listed in Annex B of the Kyoto Protocol) for the first commitment period of the Kyoto Protocol (2008-2012). The inventory on which this number is based is approved by the UNFCCC, and the Kyoto Party can (if needed) issue the AAUs.
- **Removal Units** (RMUs) – tradable units issued to an Annex B Party for the greenhouse gas removals from the atmosphere for specified sequestration activities during the Kyoto Protocol commitment period. These units are approved and issued by the UNFCCC.
- **Certified Emission Reductions** (CERs) – the Clean Development Mechanism (CDM) project- or program-based credits created in developing countries that are approved and issued by the CDM Executive Board.
- **Emission Reduction Units** (ERUs) – the Joint Implementation (JI) project- or program-based credits created in Annex B countries under their own authority (Track 1) or under the authority of the Joint Implementation Supervisory Committee (Track 2) that are issued by the Kyoto Party. ERUs are issued by converting AAUs / RMUs into ERUs so as to avoid the double counting of reductions.

3.1.4 Under the Kyoto Protocol, countries with binding targets listed in Annex B can meet some or all of their obligations through international emission trading – that is, the trading of AAUs. This government-to-government trading can be supplemented by regional, national and sub-national emission trading systems, where individual entities (corporations, facilities or other participants) can buy and sell tradable units with other system participants. These systems are important tools to allow countries or regions to meet their Kyoto Protocol or other GHG emissions reduction targets at least cost.

3.1.5 Depending on the design of the scheme, entities participating in sub-national, national or regional emission trading systems may be able to meet domestic compliance obligations by using tradable units created outside of the UNFCCC system. Therefore, the jurisdiction administering the emission trading system does not have to be a Party to the Kyoto Protocol or the UNFCCC in order to establish a system involving exchange of non-Kyoto units. These non-Kyoto units could include:

- **Allowances** – units equal to the system ‘cap’ that are freely allocated, sold or auctioned by the regulatory authority(ies); and

- **Credits** – units that are created when emission reductions or removals have been achieved; the validity of each credit is established by the regulatory authority during the credit creation process.

3.1.6 Many supranational (e.g., the EU ETS), national, sub-national and regional emission trading systems are intended to help countries with Annex B commitments meet international obligations under the Kyoto Protocol. In these cases, it is important that tradable units transferred between linked systems are backed by or can be settled with Kyoto units. The first compliance period for the Kyoto Protocol ends in 2012. The continuing presence of AAUs and other Kyoto units in the future will depend on the outcome of the next international agreement on climate change.

3.1.7 To ensure the environmental integrity of the trading system is maintained, it is crucial that the tradable units be confirmed as valid through the application of rigorous monitoring, reporting and verification requirements. If units are accepted for compliance that do not represent real reductions or removals, emissions will effectively be higher than reported.

3.1.8 For simplicity, unless explicitly stated otherwise, it is assumed in the remainder of this scoping document that:

- the scheme is a mandatory 'cap and trade' system
- the term 'tradable units' includes both allowances and credits
- the tradable units (Kyoto units and non-Kyoto units) are valid units.

3.2 Linking Mechanisms

3.2.1 An emission trading system establishes a **direct link** with another system when participants in one or both of the systems can use tradable units issued by the administrator of the other system to meet domestic compliance obligations. In other words, for those participants the tradable units of the two systems are equivalent for compliance use. The forms and variations of linking, including unilateral, bilateral and multilateral linking, are outlined below.

3.2.2 The administrator of a trading system can establish a **unilateral link** with another system by agreeing to accept tradable units issued by the other system for compliance purposes, but not vice versa.[21] A unilateral link could be easy to implement. It does not require that the two systems be "compatible" or that a bilateral agreement be completed. It does require that the user system have access to compliance units in the supplier system registry. If it is not possible to open an account in this registry, a unilateral link can still be made without the agreement of the supplying system administrator as the transfer of tradable units can be completed though a 'hold/cancel and create' action as outlined in section 3.3.3 below. In practise, however, as a result of political pressure from participants in the supplier system and to address the potential problem of the double counting of reductions, agreement of the supplier system would be valuable even if the export of compliance units is expected to be small.

3.2.3 The main effect of a unilateral link is that the in-flow of tradable units from the supplier system (depending on relative prices) reduces the price of tradable units in the system establishing the link. Depending on the relative size of the in-flow, this effect can be negligible or very significant. If there is a limit on the quantity of the tradable units from the linked system that can be used for compliance, the price reduction could be limited.

3.2.4 The administrators of two systems can establish a **bilateral link** if each accepts tradable units issued by the other system. Thus with a bilateral link, there can be two-way trade of units that are equally valid for compliance purposes in either systems. A bilateral link requires that the systems be "compatible" and some form of agreement is needed. If more than two systems

[21] Mehling, Michael and Erik Haites 2009: "Mechanisms for linking emissions trading schemes". Climate Policy, Vol. 9, No. 2, 169-184.

participate, this becomes a **multilateral link**. However, as no multilateral links have been established to date, and as a multilateral link is equivalent to two or more, possibly identical, bilateral links, this paper only considers unilateral and bilateral links.

3.2.5 Market forces will push tradable unit prices to converge in any system that allows for the trading of tradable units. When a bilateral link is established, tradable unit owners in the system with the lower price will sell to buyers in the system with the higher price. If not constrained, this trading would continue until the prices of the tradable units of the two systems are the same. In practice, however, the degree of price convergence (the amount the price of tradable units in each system changes) partly depends on the relative sizes of the systems. Linking a small system to a large system could have a negligible effect on the price of tradable units in the larger system. Restrictions on the type and/or quantity of the tradable units from the other system that can be used for compliance will also moderate the price convergence effect of the link. The price elasticity of demand and supply of greenhouse gas reductions in each system (i.e., the change in quantity in response to a change in price) could also influence the volume of trade after linking.

3.2.6 The price adjustments due to a link, which lead to lower overall net costs of regulatory compliance than if no link had been established, will create winners and losers in the linked systems. Tradable unit sellers in the lower price system and buyers in the higher price system benefit from the price convergence, while tradable unit sellers in the higher price system and buyers in the lower price system are worse off. The size of the gains and losses in each system depend on the scale of the price change in that system. Thus, although linking two emission trading systems can lower the overall cost of reaching a given greenhouse gas reduction, the potential distribution effects need to be considered.

3.2.7 A system that establishes a link with another system also establishes an **indirect link** with any other system to which the partner system is linked. An indirect link occurs without any formal or informal agreement between systems.

3.2.8 Note that the Clean Development Mechanism (CDM) and Joint Implementation (JI) are project/programme-based mechanisms under the Kyoto Protocol – they are <u>not trading systems *per se*</u>. For example, any trading system can choose to 'accept' CERs for compliance purposes – a linking agreement is not required or used. And although CERs are electronic units that only reside in a Kyoto Protocol compliant tracking system, effectively they can be made available to all trading systems (see section 3.3 below).

3.3 Tracking System or Registry

3.3.1 Tradable units usually exist as electronic entries in a **tracking system or registry**. A participant has an account in its system registry that records the tradable units it holds, transfers and uses.[22] Generally speaking, to achieve compliance with its regulatory obligation, since these tradable units must be used only once for compliance, the participant must transfer tradable units equal to its actual emissions from its registry account to the account of the regulatory authority. In a linked system a participant will transfer tradable units issued by the administrator of the other system to its own regulatory authority. However, if this transfer is not possible, an equivalent action shall be completed to ensure that the tradable units are used only once for compliance (see section 3.3.3 below).

[22] Entities with no compliance obligations, such as individuals and brokers, may also have accounts in the registry to enable them to participate in the carbon market.

3.3.2 The registries of different trading systems may be electronically linked. Where this is the case, a participant could buy tradable units from the other system and have these units transferred directly into its account in its own registry. For compliance purposes, these purchased tradable units would then be transferred to the regulatory authority's account in this registry. Note that before completing the transfer of a tradable unit, the transaction log linking the registries typically performs quality control functions such as checking the unit serial numbers to ensure the tradable units being transferred are valid, and ensuring that all requirements for the transfers of units have been met.

3.3.3 However a transaction log linking the registries is not a prerequisite for linking trading systems. For a bilateral link, the regulatory authority could agree to allow accounts to be opened in each others' registry. A participant that wishes to use tradable units from the other system opens an account in that system's registry, has the purchased tradable units transferred into this account, and as required for compliance purposes, transfers these units to its regulatory authority's account. No transfer of tradable units takes place between registries. In the absence of linked registries, a unilateral link could be implemented in the same manner as a bilateral link if the supplier system allows entities outside their system to hold accounts in their registry. Without the ability to open such accounts, the administrator of the user system may accept to create or recognize compliance units where there is evidence that an account holder in the supplier system has cancelled compliance units or will continue to hold (not sell, retire or cancel) compliance units. It is noted, however, that the supplier system could try to block this access if it determines the benefit derived from exporting compliance units is not in its best interest. So while it would be difficult or impossible to prevent unilateral linking, in practise an agreement of some sort may be necessary.

3.3.4 If the registry systems are not electronically linked, the potential for the double-counting of emissions reductions – that is, for using a tradable unit more than once, increases. It is also noted that since a bilateral link requires an agreement between the regulatory authorities, it is very likely that the registries of bilaterally linked systems will be linked electronically.

3.4 Benefits of Linking

3.4.1 The potential benefits of linking could be significant and include:

- Lower net cost of meeting the emissions cap across the two systems as a result of the flexibility to implement the lowest cost emission reduction measures across all participants.
- Increased financial incentives for entities to reduce emissions in systems where scarcity and price are increased due to linking.
- Reduced price volatility due to the creation of a larger, more liquid market for the tradable units of the linked systems.
- Reduced competitiveness concerns due to the convergence of tradable unit prices in the linked systems, as well as a reduced likelihood of carbon leakage.

3.5 Difficulties or Obstacles with Linking

3.5.1 Some of the potential difficulties or obstacles associated with linking are noted below. Many of these elements could be adequately addressed in the design of the system.

3.5.2 The net benefits of linking trading systems will rarely be evenly distributed. A link generates a convergence of prices and thus leads to a higher market price in the supplier system (as the supply of tradable units in that system decreases), and a lower price in the buyer system. It is noted, however, that in practise the effect of linking on the convergence of prices of tradable units would depend on a combination of factors including the relative price difference for achieving reductions in the two systems, the size of the market, and the additional reductions or commitments undertaken (if any) when the market is broadened through linking.

3.5.3 Linking could compromise the environmental integrity of the system with the stronger requirements. For example, if tradable units from a system with weak monitoring, reporting and verification (MRV) requirements did not achieve the intended reductions, but were nevertheless used for compliance purposes in the stronger system under the assumption that the reductions were real, the environmental integrity of the stronger system would be compromised. This issue could also arise through indirect linking when, for example, the policy decisions of one system, with respect to the type, quality or quantity of international credits or offsets it recognizes for compliance purposes, for example, are not compatible with the requirements of the system with which it is directly linked.

3.5.4 There is the potential for higher total emissions if the systems are linked than if they operate independently. This could be the result of differences in system requirements. For example, in a bilateral linked system, if the financial penalties are set at different levels, and there is no requirement to submit tradable units equal to the shortfall, effectively the lower penalty acts as a price cap for the entire system. That is, if the penalty in one system is lower than the market price, a bilateral link would create an incentive for participants in the former system to over-sell tradable units and pay the non-compliance penalty – resulting in still higher emissions.[23] [24] In addition, there could be an incentive for one or both systems to make smaller reductions to its cap over time so that its participants could remain or become exporters of tradable units in the linked system.

3.5.5 Differences in the level of ambition in systems which could have a significant impact on the availability and price of tradable units may be an impediment to linking. Similarly price caps or price interference, when present, could also be obstacles to linking.

3.5.6 These obstacles, including the possibility of higher total emissions, could be reduced or avoided by harmonizing the relevant provisions enough to make the linked systems “compatible”. Much of the literature on linking trading systems focuses on the question of the “compatibility” of the systems that could be linked.[25] With a unilateral link a certain degree of cooperation between systems is likely required. Clearly a level of compatibility will be a necessary prerequisite for any bilateral link to be established, and this compatibility would need to be sustained despite economic, technological and administrative developments over time. Sustaining the compatibility of the linked systems would require a process for agreeing on revisions to the requirements of the linked systems, a mechanism to provide assurance of the environmental effectiveness of each of the linked systems, and a procedure for terminating the linking agreement.

[23] Note that in some systems the non-compliance penalty does not take away the obligation to surrender these allowances sometime in the future.

[24] It is always the case that a financial penalty on its own effectively acts as a price cap for tradable units. There is an added dimension, however, if the financial penalties differ in a bilaterally linked system.

[25] See for example Baron and Bygrave, 2002; Haites 2003; Haites and Mullins, 2001; Jaffe and Stavins, 2007; Sterk et al., 2006; Springer et al., 2006.

3.6 Linking Trading Systems with Voluntary and Mandatory Participation

3.6.1 Though for most existing and proposed trading systems participation by specified entities is mandatory, in a few systems participation is voluntary. In some voluntary systems there are incentives to participate. For example, entities in Switzerland subject to the CO_2 tax can significantly reduce their tax payments if they join the emissions trading system. In other systems, there are both voluntary and mandatory elements. For example, under the Chicago Climate Exchange system the option to participate is voluntary but participants are then bound by a reduction target.

3.6.2 A voluntary system will rarely include all entities in the specified sectors, so the risk of an increase in emissions outside of the scope of the emissions trading system due to the constraint on emissions established by the trading system (often referred to as 'leakage') is high. If a unilateral or bilateral link between a mandatory system and a voluntary system raises the price of tradable units in the voluntary system, the incentive for leakage from that system increases. Thus a link between a mandatory system and a voluntary system creates a risk that aggregate emissions will increase, and some systems may determine that it is necessary to have a mandatory cap and trade system in place to enable linking to occur.

4. GREENHOUSE GAS EMISSION TRADING SYSTEMS

4.1 Existing Schemes

4.1.1 In this section a high-level overview of a number of the mandatory and voluntary emission trading systems that have emerged over the past decade is provided. Included is a brief discussion of the key lessons learned from the design and implementation of these systems, identification of linking arrangements that have been made between systems (if any), and where relevant a brief analysis of the implications for linking an emission trading system including international aviation with another emission trading system.

<u>Mandatory Schemes</u>

4.1.2 The **European Union** Emission Trading Scheme (EU ETS) requires each of its 27 Member States to implement emissions trading covering greenhouse gas emissions by electricity generators and specified industrial installations. More than 40% of total EU greenhouse gas emissions are covered by the scheme, increasing to over 50% from 2013. The EU ETS is of unlimited duration; the first two phases cover 2005-2007 and 2008-2012. Beginning in 2013 the trading periods will have an 8 year duration.

4.1.3 The same linking legislation applies to Phase 1 and Phase 2 of the EU ETS. During Phase 1 (2005-2007) - the pilot phase, the EU ETS did not link with any other trading system. However, in addition to the free allocation of European Union Allowances (EUAs), installations were able to use CERs for compliance. Ultimately no CERs were used for compliance. This can be explained in part by the low price of EUAs, which was the result of a) the over-allocation of allowances in Phase 1, and b) the rule that Phase 1 allowances were not bankable after 2007 (so would have no value after 2007). Note too that at the time there was no link between the UNFCCC and EU transaction logs so that CERs could not be transferred to the registries in the EU Member States.

4.1.4 In Phase 2 of the EU ETS (2008-2012) there is the possibility of full linking with other Annex B Parties to the Kyoto Protocol. As of 29 December 2007, the EU ETS legislation has been included in the European Economic Area (EEA) Agreement[26], thus making Norway, Iceland and Liechtenstein integrated members of the EU ETS with obligations to implement domestic emissions trading schemes that are compatible to the scheme in the EU Member States. In effect, the extension of the EU scheme to cover installations in Norway, Iceland and Liechtenstein constitutes full linking between trading schemes in states with separate targets under the Kyoto Protocol. The EU ETS allows for the use of CERs and ERUs for compliance purposes, though the quantity of these Kyoto units that each installation can use annually has been limited to an average of about 13 per cent of the emissions cap for Phase 2.[27] Qualitative restrictions in the EU ETS also apply; CERs and ERUs from Land Use, Land Use Change and Forestry (LULUCF) projects and nuclear projects are banned, and restrictions apply to the use of CERs and ERUs from hydroelectric projects with installed capacity exceeding 20MW.

4.1.5 Aviation emissions will be included in the EU ETS from January 1, 2012. The EU Directive requires airlines to surrender tradable units to a designated Member State for the emissions associated with flights within, into or out of the European Union.[28] For 2012 the total allocation will be 97% of the annual average 2004-2006 emissions. For the period starting in 2013, the cap will be 95% of the annual average 2004-2006 emissions. Airlines will receive approximately 82% of the allocated tradable units free, 3% will be held in a special reserve for new entrants and fast growing airlines, and the remainder will be auctioned.

4.1.6 Separate aviation allowances (EUAAs) will be created. Airlines will be able to use EUAAs, unlimited quantities of EUAs and some credits from the Clean Development Mechanism and Joint Implementation (CERs and ERUs respectively) for compliance purposes. Other sectors covered by the EU ETS will not be allowed to use EUAAs for compliance in order to maintain the integrity of the accounting system of the EU ETS since emissions from international aviation are not integrated into Member States' commitments under the Kyoto Protocol. Carbon market analysts expect EUAAs to trade at a slight discount to EUAs as they are of use to a smaller number of market participants. It is noted that while there are no restrictions on who can buy EUAA, it is expected most will eventually be used by the aviation participants for compliance.

4.1.7 Details for the EU ETS beginning in 2013 were formally adopted in April 2009, setting a single EU-wide emissions cap which reduces linearly over time, and widening the scope of the scheme. Phase 3 will enable use of CERs and ERUs in advance of a successor to the Kyoto Protocol being agreed to under the UNFCCC. The legislation includes amended rules on linking with other greenhouse gas emissions trading schemes. It specifies that bilateral links may be made with compatible mandatory schemes with absolute emissions caps in any other country or sub-federal/regional entity.

4.1.8 **Norway** implemented an emissions trading system for the period 2005-2007 that was very similar in design to the EU ETS. The Norwegian system had a unilateral link with the EU ETS and also allowed the use of CERs for compliance. Some EUAs (one transaction), but no CERs were

[26] The European Economic Area Agreement allows the member states of European Free Trade Association (EFTA) to participate in the European Single Market without joining the EU. The EEA Agreement is continuously updated with new relevant EU legislation, resulting in obligations for the EFTA States to enact domestic legislation equivalent to that which applies in the EU Member States.

[27] *Tendances Carbone*, 21 January 2008, p.3.

[28] Flights performed with aircraft with maximum take-off weight of less than 5.7 tonnes would be excluded. Commercial airlines with emissions of less than 10,000 tonnes of CO_2 or who fly less than 243 flights into, out of or within the EU within three subsequent 4-month periods would be among other exemptions.

used for compliance purposes. Like the EU ETS, the Norwegian system accumulated surplus allowances during 2005-2007. The system terminated at the end of 2007 when Norway joined the EU ETS.

4.1.9 **New Zealand** is phasing-in its emissions trading scheme over 2008-2015. The forestry sector entered the scheme in 2008. The stationary energy and industrial processes sectors and the liquid fossil fuels (transport) sector, including domestic aviation, will enter the scheme on 1 July 2010.[29] The scheme will ultimately cover all sectors, including agriculture. Participants will be able to surrender both New Zealand Units (NZUs) and Kyoto units to meet their compliance obligations although some types of CERs and ERUs will be excluded.[30] Generally there are no restrictions with regard to the import and export of units although some restrictions apply between 1 July 2010 and 31 December 2012 when a price cap is in place. New Zealand is considering the potential for bilateral links with a future Australian system.

4.1.10 **Switzerland** has imposed a tax on heating and process fuels to reduce CO_2 emissions. Large companies that agree to a legally binding emissions reduction target for 2008-2012 are exempt from the tax. Firms that agreed to emission reduction targets were allocated allowances equal to their target.[31] They may trade allowances and use specified types of CERs and ERUs to achieve compliance.[32] Allowances from approved foreign emissions trading systems may also be used for compliance. Use of foreign credits and allowances is limited to 8% of the firm's target, or up to 3 % if reductions cannot be achieved within the firm itself.[33] [34]

4.1.11 In the **United States of America** ten states in the northeast established the Regional Greenhouse Gas Initiative (RGGI) that started in January 2009. Credits are accepted from programs in RGGI states or any other US state or jurisdiction. If prices for RGGI allowances exceed a specified threshold, participants may use "allowances or credits issued pursuant to any governmental mandatory carbon constraining program outside the United States that places a specific tonnage limit on greenhouse gas emissions, or certified greenhouse gas emissions reduction credits issued pursuant to the United Nations Framework Convention on Climate Change (UNFCCC) or protocols adopted through the UNFCCC process".[35]

4.1.12 The UK Emissions Trading Scheme (2002-2006), New South Wales (Australia) GHG Abatement Scheme (2003) and Alberta (Canada) emissions management program (2007) do not have links with any other systems.

Voluntary Schemes

4.1.13 **Chicago Climate Exchange** (CCX) greenhouse gas emission trading system is voluntary but members are required to adopt binding limits for their greenhouse gas emissions. The CCX created a unilateral link to the EU ETS, allowing up to 1000 EUAs per participant to be used for CCX compliance. In May 2006, a participant in both the CCX and the EU ETS transferred 100 EUAs to a CCX account in the United Kingdom; the CCX retired the EUAs and issued 100

[29] Further details can be found at www.climatechange.govt.nz
[30] CERs and ERUs relating to nuclear projects cannot be used for compliance, nor can lCERs and tCERs from LULUCF projects.
[31] Switzerland, 2008. *Startschuss zum Emissionshandel in der Schwitz.* Bundesamt für Umwelt, 11 June 2008, Berne Switzerland [available at http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=de&msg-id=19266].
[32] Credits for afforestation and reforestation with genetically modified or invasive species are excluded.
[33] Swiss Federal Council, 2005. *Verordnung über die Anrechnung de rim Ausland erzielten Emissionsvermunderungen* (CO□□nrechnungsverordnung), 22 June 2005 [available http://www/admin.ch/ch/d/sr/6/641.711.1.de.pdf].
[34] Note: Switzerland has also stated its intentions to link with the EU ETS in the future.
[35] RGGI, 2006. The Model Rule defines this "stage two trigger event" as a sustained allowance price of $10 or more for two consecutive 12 month periods, adjusted for inflation relative to 2005.

allowances into the participant's CCX account. Prompted by the dramatic drop in EUA prices during 2006, the CCX decided in December 2006 that Phase 1 EUAs would no longer be accepted for compliance with 2006 and 2007 CCX obligations. The CCX also accepts CERs for compliance, subject to approval on a project-by-project basis by the CCX Offsets Committee.

4.1.14 **Japan** launched a voluntary emissions trading system (JVETS) in 2005 involving 31 participants; the commitment period and trading began in 2006. Participants were offered an incentive of approximately US$10/t$CO_2$ to participate. The JVETS did not link with any other system. However, participants were allowed to use CERs to achieve compliance, though none were used. The program ended in 2007.

4.1.15 In 2008, Japan commenced the trial of a new voluntary emissions trading scheme for the 2008–2012 period. Over 500 companies signed up to participate. Targets were submitted by each company for approval by the government. Companies that manage to exceed their CO_2 emission reduction targets can trade their surplus credits to other companies in the scheme to use for compliance purposes. There are no penalties for not meeting targets. This scheme does not link with any other system.

4.2 Future Schemes

4.2.1 More jurisdictions are implementing emissions trading systems and links between systems continue to attract the interest of policy makers. Reflecting the high level of interest in linking, more than 15 national and regional governments launched the International Carbon Action Partnership (ICAP) in October 2007 as a "forum to discuss relevant questions on the design, compatibility and potential linkage of regional carbon markets"[36]. Monitoring, reporting, verification, compliance and enforcement issues and options and issues related to auctioning have for example been examined by ICAP. To date, ICAP has 25 members and 3 observers.

4.2.2 **Australia** released a White Paper in December 2008 which outlined the design of a *Carbon Pollution Reduction Scheme* - a cap-and-trade system that would cover approximately 75% of Australia's greenhouse gas emissions, commencing 1 July 2011. The draft legislation outlined in the White Paper proposed that CERs, ERUs and RMUs be accepted for compliance by regulated firms.[37] Future bilateral links would be considered based on a range of criteria including an internationally acceptable (or mutually acceptable) level of mitigation commitment; adequate and comparable monitoring, reporting, verification, compliance and enforcement mechanisms; and compatibility in design and market rules. There would be no export of Australian allowances unless (a) a five-year advance notice was provided, or (b) the allowances are exported as part of a bilateral linking agreement where trading was not anticipated to have an adverse effect on carbon prices. The draft legislation for the scheme was defeated in parliament in December 2009. The government has indicated it will reintroduce the draft legislation in 2010.

4.2.3 **Canada** has committed to reducing its total greenhouse gas emissions by 20% from 2006 levels by 2020, and 60-70% by 2050. To assist in achieving this target, Canada is in the process of developing detailed cap and trade policies that would enable harmonization with the U.S. cap-and-trade policy beginning to take shape in Congress. Canada is also developing draft

[36] ICAP Political Declaration (2007) available on ICAP's website (http://www.icapcarbonaction.com/index.php?option=com_content&view=article&id=12&Itemid=4&lang=en)

[37] Australia, Commonwealth of, 2008. *White Paper: Carbon Pollution Reduction Scheme, Australia's Low Pollution Future,* December 2008, Canberra, Australia [available at http://www.climatechange.gov.au/whitepaper/report/index.html]

greenhouse gas regulations that could be harmonized with a broad range of possible future actions in the U.S. The Government of Canada has also signalled interest in potentially linking the Canadian program with other existing or future trading systems.

4.2.4 In the **United States of America** both chambers of Congress have been working on the development of legislation that would establish a national greenhouse gas emission trading system. On June 26, 2009, the House of Representatives passed the *American Clean Energy and Security Act of 2009* (ACESA), which would establish a cap-and-trade system for greenhouse gases. If the Senate passes its own legislation, the House and the Senate will establish a Conference Committee to develop a compromise bill that would then require the approval of Congress.

4.2.5 ACESA would cap the greenhouse gas emissions of entities responsible for approximately 85% of U.S. emissions once the sector phase-in is complete. It is proposed that the phase-in begin in 2012 and be completed in 2016. Covered entities include refineries, electric generators, natural gas distributors, and industrial facilities.[38] Allowances from certain "qualifying" international climate change programs run by foreign governments may be used for compliance under certain conditions. These conditions include the imposition of an absolute tonnage limit on emissions that is at least as stringent as that imposed by the U.S. under the ACESA.[39]

4.2.6 Regional initiatives in North America, including the Western Climate Initiative (WCI) and the Midwestern Regional Greenhouse Gas Reduction Accord, could lead to establishment of emissions trading systems covering multiple American states and Canadian provinces. Individual states and provinces, including California and British Columbia, are developing emissions trading systems that could be independent or part of a regional initiative. All of the proposals that have considered linking favour its adoption in some form.

4.2.7 **South Korea, Mexico** and the **Ukraine** have also expressed interest in establishing emissions trading schemes, but details have not yet been worked out.

4.3 Opportunities for Linking

4.3.1 With more emission trading systems in operation there will be more opportunities for linking. The EU, Swiss, New Zealand and Australian systems were intended to help comply with Kyoto Protocol obligations, and all are potential candidates for bilateral links. However a decision on whether any of these schemes are compatible is still to be made. In addition, regional systems such as RGGI and the WCI that are not designed to assist with Kyoto compliance are mandatory cap and trade systems that also have the potential for linking. Several of these systems have expressed a willingness to explore bilateral links, but discussions are still at an exploratory stage. The potential for a bilateral link of a cap and trade system with an emission intensity system is also being explored.

[38] In each category, it is only entities surpassing certain threshold limits that are covered under the cap-and-trade program.
[39] The program must also include provisions to ensure comparable monitoring, compliance, enforcement, quality of offsets and restrictions on the use of offsets.

5. LINKING TRADING SYSTEMS INVOLVING INTERNATIONAL AVIATION

5.1 Introduction

5.1.1 International aviation has unique features that must be considered when developing an open emissions trading system that includes the sector as they could affect the willingness of other emissions trading systems to link. Some of these features have been briefly considered earlier in the paper and include:

- the climate change impacts of aviation emissions; and
- the status of the international aviation tradable units.

5.1.2 Aviation emissions have climate change impacts in addition to those caused by CO_2 emissions. However, it would be difficult to include the non-CO_2 effects such as NOx, contrails and water vapour in a trading system as there are many scientific uncertainties related to these effects, their duration, and their variability over time and location. On the other hand, aviation tradable units for CO_2 emissions might be regarded as permitting a larger climate change impact than from CO_2 only. Other emission trading systems might be reluctant to link with an international aviation trading system or a system that includes international aviation because of the difference in the climate change impacts associated with their respective tradable units.

5.1.3 Many emissions trading systems for greenhouse gases are intended to help the country meet a national emissions limitation commitment under the Kyoto Protocol. It is important for such trading systems that the tradable units transferred between linked systems be settled in Kyoto units. In any emissions trading system that includes aviation, Kyoto units from the Clean Development Mechanism or Joint Implementation could be accepted for compliance purposes. However, access to these units is separate from the linking discussed in this report.

5.1.4 The tradable units used by a separate international aviation emissions trading system would not be backed by Kyoto units unless there was an agreement under the UNFCCC. Thus schemes that include emissions from international aviation as well as other sectors may have unique aviation and non-aviation tradable units and may restrict the type of tradable units that can be used for compliance by the aviation sector and other sector participants in the system. In addition, an emissions trading system for aviation could accept for compliance purposes project-based credits (‘offset credits’) from emission reductions achieved by uncovered sources that are issued through its own processes. The institutional capacity to ensure the environmental integrity of these offset credits, including avoiding double counting with other parallel systems, would be required. However, a mechanism that allows the international aviation emissions trading system to issue tradable units that are accepted for compliance with an international obligation (e.g., Kyoto units) could be a prerequisite for a bilateral link with many other systems.

5.1.5 In general, international aviation could be included in an ‘open’ emission trading system in one of two ways:

- including some/all international aviation emissions in a national or regional emissions trading system that covers emissions from other sectors; or
- establishing an emissions trading system for some/all international aviation emissions and linking this system to one or more emission trading systems that involve

emissions from other sectors. With reference to section 2.3.2, it is noted that a system covering only international aviation would only be created with the precondition that it will be linked to one or more emissions trading systems involving other sectors.

5.1.6 Thus in sections 5.2 and 5.3 below, the following two models for linking are briefly discussed:

1) links between national or regional trading systems that cover some international aviation emissions; and
2) links between a system that covers some/all international aviation emissions and a national or regional trading system.

5.1.7 And then, as many issues related to linking would apply to either model, additional points to consider are set out in section 5.4.

5.2 Linking National or Regional Trading Systems that include the International Aviation Sector

5.2.1 If international aviation emissions are covered by a national or regional trading system, the sector will be integrated with the other sectors in the system. However, some restrictions may be imposed on use of aviation allowances by other sectors involved in the same emission trading system. For example, there could be internal barriers or gateways that restrict transfers to/from the international aviation sector. In addition, allowances for aviation emissions may not be totally fungible with other tradable units in that system. This will occur, for example, as long as international aviation emissions are not included under the UNFCCC framework and thus cannot be backed by the UNFCCC budget currency (AAUs).

5.2.2 Regardless of how international aviation emissions are covered, however, if these national or regional systems link with other systems, unilaterally or bilaterally, the international aviation sector will also be linked to those other systems either directly or indirectly.

5.2.3 Only the EU ETS has a legal requirement to incorporate both national and international aviation emissions into a regional trading system. If the EU ETS links with another national or regional system, all participants in the EU ETS, including the international aviation sector, would be linked with that national or regional system directly or indirectly. If the linking agreement allows companies subject to the EU ETS to use for compliance the units of the linked system (Australian allowances for example), there would be a direct link.[40] If the linking agreement does not change the list of tradable units that companies subject to the EU ETS can use for compliance (a less likely scenario), there would still be an indirect link due to the convergence of tradable unit prices including EUAs.

5.2.4 Other national and regional trading systems might use a different approach to cover international aviation emissions. The New Zealand system, for example, will cover emissions in the (liquid fossil fuels) transport sector at the point where refined oil products leave the refinery or are imported. Fuel suppliers will have to surrender units corresponding to the emissions that arise when

[40] The linking agreement would have an impact on the price of EUAAs and EUAs.

the fuels are combusted - an upstream approach. A simple way to expand the system to cover international aviation emissions would be to include fuels used for international aviation.[41]

5.2.5 It may be difficult to coordinate national trading systems in order to ensure a large part of global international aviation emissions are covered. However, this coordination could be significantly less of a challenge than would be required to develop an aviation-only emissions trading system that is linked to other systems. Furthermore, larger emission trading schemes may find it easier to operate bilaterally. Negotiation of a link between two parties, such as the EU ETS and potentially a future U.S. ETS would be easier than negotiating linking arrangements with a large group of parties. If aviation were included in both the U.S. and EU emission trading systems, a significant proportion of international aviation emissions would be captured. However, the need for more universal coverage to avoid artificial competitiveness advantages outside of these schemes may persist.

5.3 Linking a Trading System for International Aviation with a National or Regional Trading System

5.3.1 This section briefly covers the case of linking an emission trading system for international aviation only (a closed system) with other emission trading systems. It is important to note here that it is the basic premise of this scoping paper that a closed system for international aviation would not be created unless there was certainty that it would be linked to a system involving other sectors so as to make it an open system.

5.3.2 Issues related to the organization of the international aviation emissions trading system and the detailed elements of that system would need to be addressed. For example, with an international emissions trading system for aviation covering more than one State, the form of the agreement between States, the authorities that might best be centralized, and the system elements to manage the competitiveness impacts of excluding some markets (if a desirable feature) would need the agreement of all participating States. The ability to control these features in an aviation emissions trading system will, however, be attractive to many States. At the same time, States would also have to agree, probably unanimously, on the emissions trading systems it will link to and the design of these links. It is noted that the openness of this system would be enhanced as more links to emissions trading systems are added.

5.3.3 The choice of system(s) to link with an aviation emissions trading system would depend on:

- the perceived quality of the tradable units and the environmental integrity of the target system (based on the stringency of the cap and other system requirements);
- the ease of establishing a link with the target system and willingness for the target system to establish a link; and
- the size of the target system relative to the projected demand for external tradable units by the trading system for international aviation emissions.

[41] New Zealand allows some large aircraft operators operating domestic flights to opt in to the scheme, i.e. in such cases they can take over all emissions trading scheme obligations and liabilities from their fuel suppliers.

5.3.4 An international aviation trading system could establish a link with an emission trading system in a country that has an emissions limitation commitment under the Kyoto Protocol. Depending on the design of the emissions trading system in question, this link could provide access to high quality Kyoto units. To avoid double counting reductions and thus maintain the environmental integrity of the system, these Kyoto units must be cancelled when used for compliance by participants in the international civil aviation system. Though it could be possible to manage this cancellation via a unilateral link, the cooperation of the government(s) involved may be required. For example, if linked with the EU ETS, the cancellation of Kyoto units will require the co-operation of Member States as the allowances in the EU ETS have recently been separated from the associated Kyoto units.

5.3.5 It is noted that the unilateral linking scenario would not be likely for a scheme that covers international aviation emissions associated with all ICAO States. This is because the target schemes for the unilateral link would be controlled by one or more of these ICAO States. In this scenario, these States would be agreeing to unilaterally link with their own system. Though hypothetically possible, in such a case a bilateral link seems a much more likely scenario.

5.3.6 At present only the EU ETS (in combination with the Clean Development Mechanism) would likely be large enough to provide for the projected demand for external tradable units by a trading system for international aviation emissions.[42] However, a national trading system established in the U.S. or links with a number of smaller systems may also be sufficient to meet the projected demand.

5.4 Other Issues related to Linking Systems Involving International Aviation

5.4.1 Establishing a unilateral link with most systems not linked with the Kyoto Protocol could be relatively simple. As discussed in section 3.3, the registry for the system involving international aviation could be linked electronically with the target registry if the registry administrator of the target registry is co-operative. In the absence of an electronic link, the administrator of the system involving international aviation could establish an account in the registry of the target system. (It is noted that the New Zealand and proposed Australian systems, for example, do not allow the export of their emission units.) Tradable units used for compliance could be cancelled in the registry of the target system. Difficulties would arise if external entities, such as the administrator of the system involving international aviation, are not able to establish or effectively operate an account in the registry of the target system.

5.4.2 Furthermore, as discussed above, participants in other systems may be concerned about the increased compliance cost they would face if a unilateral links with an international aviation emissions trading system is established. If the link will provide the aviation sector with access to lower cost credits from the target scheme, and it is expected that the demand tradable units through the link would be high, there could be political pressure for the Government running the target system not to co-operate. In this case a bilateral linking agreement may be necessary to prevent the target scheme erecting measures to disrupt the functioning of the link

5.4.3 A bilateral link would require that the system involving international aviation emissions and the other system(s) be sufficiently “compatible.” (Compatibility issues are discussed in Chapter 6.) A bilateral link would also require there be an agreement between the regulatory authorities of

[42] There are implicit assumptions here about the carbon price in the aviation emissions trading system.

the two systems. The difficulty getting an agreement would be further complicated if the benefits of linking and thus the importance of completing a linking agreement are significantly different between the negotiating parties. That is (as discussed in sections 3.2.2 and 3.2.5), although the prices of tradable units move toward convergence and the net cost of reaching the combined environmental objectives of the two systems is reduced when the systems are linked, the distributive effects of the link may be undesirable to some participants.

5.4.4 Reciprocal unilateral links may be a way to avoid the complex issues raised by a bilateral link. A trading system involving international aviation emissions and another system, such as the EU ETS, could agree to establish unilateral links with each other or with a third system, such as future U.S. emissions trading system. The advantages of multiple unilateral links could include the following:

- Unilateral links could be easier to implement, particularly when considering linking with new systems. The systems would not need to be as fully harmonized and a formal linking agreement may not be needed.
- Unilateral links could be easier to change if needed. For example, each system could change the list of tradable units it accepts using its internal procedure. As noted, the CCX decided to no longer accept EUAs when the price of these units collapsed as a result of over allocation in the EU ETS.
- Linking could be approached gradually. Quantity restrictions could be applied to the other system's tradable units initially and be loosened over time as the effects of the link become clearer.

5.4.5 The economic benefits (i.e., lower tradable unit price) of reciprocal unilateral links will not differ significantly from a bilateral linking agreement.[43] With reciprocal unilateral links, one system would be a net importer of tradable units from the other. Absent restrictions on the quantity of tradable units that can be imported (or exported), tradable unit prices in the two systems will tend to converge. If two systems are unilaterally linked to a third, or use significant quantities of Clean Development Mechanisms credits, prices will tend to converge as long as the caps of the two systems are such that both are net importers of tradable units from the third system or the CDM and there are no restrictions on the quantities imported.

5.4.6 And while it may be possible for national and regional trading schemes to link unilaterally or bilaterally as discussed above, some forms of linking could be restricted by national legislation. For example, the EU ETS legislation is clear that only bilateral links with another trading scheme could be considered.[44]

5.4.7 It is also noted that even if national and regional systems agree to coordinate coverage of international aviation emissions, different approaches might make this difficult in practice, and could potentially lead to issues of emissions being counted twice or not being covered at all. For example, airlines that are included in the EU ETS could be covered by a different system based on the carbon content of the aviation fuel sold in a State outside the EU. For this reason the EU ETS legislation provides a clear mechanism by which incoming flights can be excluded should equivalent measures be adopted by other countries or regions. Differences in the share of tradable

[43] Note that the benefits would involve lower overall economic costs of achieving the reductions across the two systems, but allowance prices and economic costs in the supplier system may go up. While the overall economic benefits may exist, the supplier system may not wish to participate if these benefits represent a transfer from it to another system.

[44] Article 25 of Directive 2003/87/EC as amended

units auctioned also could also pose difficulties. For example, the EU ETS might continue to distribute a portion of the tradable units free, but making fuel refiners and importers responsible for the carbon content of aviation fuels would be equivalent to auctioning all of the tradable units for international aviation.[45] Thus depending on the levels of cost pass through to customers in the industry, levels of potential windfall gains in the sector could vary.

5.5 Legal Issues

5.5.1 Many and perhaps most links will require some form of agreement between the systems. The agreement must balance the competing objectives of "leaving each government with sovereignty over its own system while providing linking partners adequate authority to influence those changes in linked systems that would materially affect their own system". (Jaffe and Stavins, 2007).

5.5.2 Where divergent interests and other uncertainties generate demand for predictability and stability, a binding agreement will be preferred. Such an agreement could be an international treaty, though other forms of legal agreement could be possible. Agreements that might be established under the umbrella of ICAO have not been assessed as part of this scoping study.

5.5.3 The agreement must reflect the consent to be bound, as expressed for example by signature or ratification. And aside from a provision specifying the recognition of tradable units, the agreement would need to include from the outset:

- provisions to address legal issues such as equivalence;
- a mechanism to provide assurance of the environmental effectiveness of each of the linked systems or of the aggregate system as a whole;
- a process for revising the requirements of the linked systems;
- a process to resolve disputes arising under the agreement; and
- a procedure for terminating the linking agreement .

5.6 International Trade Issues[46]

5.6.1 Much has been written about the potential for conflicts between emissions trading systems established to meet Kyoto Protocol commitments and various World Trade Organization (WTO) agreements.[47] Though an assessment of potential conflicts would be an important part of any system design, no significant issues or problems have so far emerged.

5.6.2 Trading compliance units, which are effectively permits to emit greenhouse gases in an emissions trading system, is not covered under General Agreement on Tariffs and Trade and the General Agreement on Trade in Services rules as these units are not considered either goods or services.

[45] The fuel suppliers are likely to increase the price of the fuel sold to reflect the market value of the allowances needed for compliance. The effect for the airline is similar to buying the necessary allowances.

[46] Based on an input paper by Aniel Bangoer (Climate Change and Industry Directorate, Dutch Ministry VROM).

[47] The General Agreement on Tariffs and Trade allows states considerable policy space to develop trade measures for environmental reasons. These measures may be unilateral, and while states need to try to get multilateral consensus, there is no WTO requirement that these efforts succeed, so long as they are made in good faith. The Korea beef, EC-Asbestos and US-Shrimp I case demonstrate that WTO jurisprudence would permit trade related measures aimed at climate stabilization, under certain conditions.

5.6.3 There is some question whether free distribution of tradable units to participants in an emissions trading system could be considered an actionable subsidy since a transfer of resources (tradable units) can be a subsidy.

5.6.4 The key issue raised in linking trading systems is whether the arrangement discriminates against potential tradable unit exporters in systems that are not included in the link. In the ICAO context, non-discrimination is crucial.

6. HARMONIZATION ISSUES RELEVANT FOR LINKING

6.1 Introduction

6.1.1 Much of the literature on linking trading systems focuses on issues related to the requirements for and the potential impacts arising from the "compatibility" of the systems that are considering linking.[48] A bilateral link requires that the designs (or rules) of the two trading systems be harmonized enough to make them "compatible". All the design elements covered in this chapter are of importance for a bilateral link. Although a unilateral link does not require the same level of compatibility, in practice it will be important that certain elements of the systems are harmonized. Thus each element discussed in this section should be assessed when considering any form of linking.

6.1.2 From a technical perspective, harmonization of the system designs to enable a bilateral link may be essential for only a relatively small number of provisions, such as a price cap. However, for political reasons, harmonization of several other provisions, such as the method for allocating tradable units and use of offsets, is desirable and possibly essential.[49] This is because a bilateral link effectively allows participants in one system access to many provisions of the other system.

6.2 Design Elements relevant for the Total Emissions of Linked Systems

6.2.1 Differences between systems in the following provisions could lead to higher total emissions after a bilateral link is established compared with the independent operation of systems:

- cost containment measures
- non-compliance penalties and enforcement
- borrowing and banking restrictions
- compliance period and life of tradable units
- form of the emissions limit
- measures to address leakage

A number of key design issues are considered below.

[48] For more information see, for example Baron and Bygrave, 2002; Haites 2003; Haites and Mullins, 2001; Jaffe and Stavins, 2007; Mace et al., 2008; Sterk et al., 2006; Springer et al., 2006.
[49] See Mace et al. 2008.

6.2.2 **Cost Containment.** The cost of meeting the system emissions limit is uncertain. To manage what could be excessive price volatility or excessive costs for system participants, some systems adopt a price cap or “safety valve”. A safety valve is a relatively high price at which the system administrator commits to selling enough additional tradable units to enable participants to comply with their regulatory obligation. This allows total emissions to exceed the original limit or hard cap (assuming there is no a set-aside or the set aside proves insufficient for this purpose). If the safety valve price in one system is lower than the market price after it is linked with another system, additional tradable units would be issued until the market price for the linked systems fell to the level of the safety valve. A price cap is therefore an obstacle to linking. Eliminating the price cap mechanism can address the issue.

6.2.3 **Non-compliance penalties and Enforcement.** Most trading systems have a non-compliance penalty that consists of a “make good” provision – an obligation to provide tradable units some time in the future, plus a financial penalty - $X per tonne of excess emissions. Such a regime ensures that compliance is always less costly than non-compliance. It also protects the environmental integrity of the system, since all emissions are covered by tradable units.

6.2.4 A financial penalty alone can allow higher total emissions and if set too low can act as a price cap. For example, if one system has only a financial non-compliance penalty, and this penalty is lower than the market price for tradable units after linking with another system, participants would have an incentive to sell tradable units into the other system and pay the penalty for non compliance. It is noted that, as most firms would be uncomfortable profiting from deliberate non-compliance, the impacts of this behaviour could be small.[50] However, harmonizing the financial penalties may be difficult because the trading systems are in different jurisdictions. The penalties will be defined in the respective currencies of the jurisdictions and the exchange rate will fluctuate over time. Differences in the inflation rates will also affect the penalties of the two systems over time. The best way to prevent an increase in total emissions due to the non-compliance penalty is for each system to adopt a penalty that consists of a tradable unit plus a financial penalty. Financial penalties should also increase over time.

6.2.5 In addition, the rules related to ensuring compliance with the emissions constraint and the rigour of their enforcement could have a significant impact on the environmental outcome of the regimes whether independent or linked. Of interest here is the potential for moving tradable units between systems in order to gain advantage from the system where the requirements and rigour of enforcement are more lax. The more harmonized the systems, the less scope there is for this type of ‘gaming’.

6.2.6 **Borrowing.** A borrowing provision permits a participant to use tradable units for a future period toward compliance for the current period.[51] For example, a participant could use tradable units from the 2011 compliance period to meet its regulatory obligations for 2009. Where there is sufficient liquidity in the market to provide system participants with the units they will need for achieving compliance without invoking excessive price volatility, a borrowing provision is not needed. Systems that allow borrowing usually limit the amount that can be borrowed and impose other requirements.

[50] See Baron, R., and Bygrave, S., 2002. *Towards International Emissions Trading: Design Implications for Linkages*. Organization for Economic Co-operation and Development (OECD) and International Energy Agency (IEA), Paris, France.

6.2.7 If the participant does not repay the borrowed tradable units (e.g. because the participant has ceased operation), emissions will exceed the emissions cap. If a system with a borrowing provision has a bilateral link with another system, the borrowing provision becomes accessible, indirectly, to the participants in the other system. That is, participants with access to the borrowing provision can sell tradable units to participants in the other system and borrow to achieve their own compliance. Thus a borrowing provision in only one of the linked systems increases the risk that over time total (aggregate) emissions will exceed the emissions cap. Extending the compliance period or elimination of the borrowing provision could address the increased risk that comes with the bilateral link. Other ways to reduce the risk are to harmonize the borrowing provisions and to design the system to maximize the probability of repayment.

6.2.8 **Banking.** A banking provision permits tradable units issued for one compliance period to be saved for use during a subsequent compliance period. If the emissions cap of each system is lower than its projected emissions, banking yields both environmental and economic benefits. Banked tradable units mean emissions have been reduced more than required in the near term though they will be higher (and may exceed the cap) when the banked units are used. Banking also contributes to greater liquidity and price stability. Most trading systems allow unlimited banking.

6.2.9 A system whose emissions cap may be higher than the projected emissions may limit banking so that emissions during each period are constrained by the cap for the period. (This is more likely during the early years of a trading system.) If a system that allows unlimited banking has a bilateral link with a system that limits banking, the banking provision becomes available to all participants. The result may be higher total emissions. More stringent emission caps for the system that limits banking is the most effective way to address the potential increase in emissions due to a bilateral link.

6.2.10 **Compliance Period**. Most trading systems use the calendar year as their compliance period. At the end of the year entities must remit tradable units equal to their actual emissions during the year. However, the compliance periods of systems with a bilateral link could have different end dates and/or be of different lengths. The "overlapping of compliance periods" can allow for short-term borrowing. An entity with an earlier compliance date can buy tradable units from an entity with a later compliance date. If the seller ceases operation before its compliance date and has therefore no obligation to cover their tradable unit shortfall, total emissions will have been increased. Harmonization of the compliance periods is the best way to address the potential increase in emissions due to a bilateral link. Establishing a compliance reserve - a minimum quantity of tradable units that must be retained in a participant's registry account, is another way to address this potential problem.

6.2.11 **Life of Tradable Units**. The life of a tradable unit is the period during which it can be used for compliance purposes. A limited tradable unit life is similar to limited banking. If a system with a short tradable unit life has a bilateral link with a system with a longer tradable unit life, all participants can use the tradable units with the shorter life for compliance and bank those with a longer life. As a result fewer tradable units may expire unused and in this case total emissions would be higher. Harmonizing the tradable unit life and banking provisions is the only way to address the potential increase in emissions due to a bilateral link.

6.2.12 **Absolute Caps and Intensity Targets.** The emissions cap for a period may be an absolute quantity (X tonnes of CO_2) or a function of production (Y tonnes of CO_2 per unit produced multiplied by the number of units produced). An absolute cap guarantees the environmental outcome. An intensity target could result in a better or worse environmental outcome depending on the stringency of the target and the level of production (e.g., during an economic downturn there would no over-allocation of compliance units as often occurs within a capped system). Though the allocation of tradable units under a capped system could be gratis or via auction, an intensity target implicitly involves a free allocation of tradable units. As a result of these and other differences, it could be significantly more difficult to negotiate a link between systems if one has an absolute cap and the other has an intensity cap. Some systems, such as the EU ETS, require a mandatory cap for linking.

6.2.13 **Leakage**. Leakage occurs if implementation of the trading system leads to increased output and emissions by sources outside the trading system. For example production could be transferred to entities whose emissions are below the threshold for participation in the emissions trading system or to entities in other jurisdictions. A bilateral link would tend to increase the tradable unit price in one jurisdiction and so provide a stronger incentive for leakage from that system. However, it also tends to lower the tradable unit price and the incentive for leakage in the other jurisdiction. Though the net effect of leakage is not known, it would be desirable to avoid the implementation of border measures or other means designed to reduce the impact of leakage. The harmonization of sources covered and harmonization of thresholds for participation in the emissions trading systems will help reduce the risk of increased leakage (if any) due to a bilateral link.

6.3 Design Elements relevant for the Acceptance of Linked Systems

6.3.1 As discussed in section3.2, a bilateral link requires the agreement of governments that control the two systems. Thus a decision to establish a bilateral link is ultimately a political decision. Though a government is unlikely to agree to establish a link with a system it perceives to be less ambitious (as it would create pressure to make its system similarly less ambitious), it is important to note that the stringency of a system has various aspects. These include, among other elements, the scope of the system, the emissions constraint, the method of distributing tradable units, the types and quantities of emission reduction credits available for use by participants, and the monitoring, quantification and verification methods participants must use.

6.3.2 Thus while differences between systems in the following provisions would not result in higher total emissions due to establishment of a link, harmonization is desirable, perhaps crucial, to gain acceptance for the linking of the emission trading systems:

- coverage of the system
- emissions constraint
- distribution of tradable units
- use of offsets
- monitoring, reporting, and verification requirements
- gateways
- government intervention

6.3.3 **Coverage.** One system may include different categories of sources than the other system. Such differences can raise political concerns related to competitiveness and fairness and so inhibit the willingness to link. For example, a sector covered only by the system with a lower price prior to linking may object to a proposed link on the grounds that compliance would become more costly and competitors in the other jurisdiction would not be affected. The same concern applies to differences in the accountable entities and the threshold for participation. An industry may feel disadvantaged if one system holds large industrial sources responsible for their emissions while the other places the responsibility on fossil fuel suppliers.[52] Differences in thresholds would mean that sources in some size ranges are covered in one system and exempt in the other. In making an assessment of comparability, it is however also important to look at measures which complement the emission trading system. For example, a sector that is not included in one of the emission trading systems may be regulated by other measures that lead to equivalent impacts.

6.3.4 **Emissions Constraint.** Both the nature and level of the emissions constraint influence the real and perceived stringency of a system. Though linking systems – one with an absolute cap and one with an intensity cap may be difficult (the latter has no absolute limit on emissions), it is not necessarily the case that an intensity cap is less stringent than an absolute cap.[53] For example, during an economic downturn many allowances under an absolute cap could be surplus to participants needs but such a surplus could not be generated in an emissions intensity system.

6.3.5 In an unlinked trading system, the marginal cost of abatement that drives the carbon price can be used to assess the stringency of the target. The percentage reduction from projected emissions needed to achieve the cap, and the total cost of abatement measures already implemented under the cap, could also be considered valid indicators of the stringency. After a bilateral link has been established, the net export of tradable units can be used as an indicator of the stringency of the caps, though net changes in the size of the tradable unit banks must also be taken into consideration.

6.3.6 Harmonization of the type of cap may be necessary to gain political support for a bilateral link. Mandatory cap and trade systems are generally only willing to link with other mandatory cap and trade systems.

6.3.7 **Allowance Distribution.** Any combination of free allocation and auctioning can be used to distribute tradable units in a capped system. Free allocation requires rules to determine the quantity awarded to each recipient. With different rules, comparable recipients in the two systems may receive different quantities of these tradable units. This problem disappears if all the units are auctioned. Common rules for the accountable entity and the threshold for participation facilitate the comparison of allocation rules. For this reason harmonization of the rules for identification of the accountable entities, setting thresholds, and the allocation of allowances may be necessary to gain political support for a bilateral link. It is important to note that the method of allocation within a cap does not affect the cap or the environmental integrity of the system.

6.3.8 **Offsets.** Participants may be able to use credits awarded for emission reductions outside the scope of the regulatory system for compliance purposes. The types of emission reduction actions eligible to earn credits, and the quantity of credits participants can use for compliance, influence the stringency and perceived integrity of the system. Some types of emission reduction actions may be politically contentious in a particular country (e.g., some countries oppose the use of credits from nuclear power projects and from forest projects), and so recognising these for compliance may inhibit the willingness of other systems to link. Common rules with respect to the creation and use of offset credits will facilitate linking.

[52] It is not obvious which approach would favour a particular industry, but the treatment is different and comparison of the treatment is difficult so it is easy for a firm to argue that it is at a disadvantage.

[53] See Herzog, T., Baumert, K., and Pershing, J., 2006. Target: Intensity. An Analysis of Greenhouse Gas Intensity Targets, World Resources Institute, Washington, D.C., November.

6.3.9 **Monitoring, Reporting, and Verification**. Participants in an emissions trading system must monitor or calculate their actual emissions (and also their production in an emission intensity system) and report them to the regulatory authority. Some systems require that the reported emissions (and production) be verified by an accredited independent body. The regulatory authority then assesses compliance and imposes non-compliance penalties for excess emissions. Concerns about the quality of emissions data would raise questions about the integrity of the system and undermine faith in the value of the tradable units. Differences in the MRV requirements and compliance assessment procedures between two systems could also raise competitiveness concerns.

6.3.10 The systems required for MRV do imply costs for the companies covered by the systems and for the administration responsible for approving the reports submitted by participants. However good MRV is essential for successful linking. A bilateral link would create a requirement to ensure the MRV rules and compliance assessment procedures are comparable and of sufficiently high quality.

6.3.11 **Gateways**. Some trading systems include "gateways" to control the flow of specific tradable units. For example, the EU ETS has a gateway (a temporary arrangement) to prevent a net inflow of tradable units from Cyprus and Malta because they are not Annex I Parties to the Kyoto Protocol.[54] Note that when international aviation is included in the EU ETS, industrial participants will not be able to use the aviation tradable units for compliance. This restriction to one-way trading is however different from a gateway that manages the quantity of tradable units moving between participants or systems.

6.3.12 Gateways have the potential to restrict trade. They can lead to price differences on either side of the gateway, which reduces economic efficiency. However where a gateway exists there is usually an important practical reason for its establishment. Gateways probably would need to be maintained if a bilateral link is implemented. A bilateral link might even create political pressure for additional gateways.

6.3.13 Thus when aviation is included in the EU ETS, a bilateral link of the EU ETS with another system should not allow industrial sources in that system to use aviation tradable units for compliance as that would not be consistent with the restriction on the use of those tradable units by industrial sources in the EU ETS.[55] A system for international aviation may wish to establish a gateway as part of a bilateral link with another trading system. For example, the international aviation system may wish to prohibit a net outflow of tradable units from its system. Such a gateway could be implemented through the transaction log linking the registries of the two systems or through the linking agreement with the other system – participants in that system would not have access to aviation tradable units for compliance purposes when the gateway is closed.

6.3.14 **Government Intervention.** When systems are linked, actions that affect one system have consequences for participants in both systems. Government intervention, such as an ex post adjustment to allowance allocations or a price intervention, would have consequences for tradable unit prices and competitiveness. Systems may be reluctant to establish a link with a system that has a history of this kind of government intervention.

---

[54] To ensure that international trades of EUAs do not affect a Member State's compliance with its Kyoto Protocol commitment, such trades must be accompanied by an equal transfer of EU AAUs. Since Cyprus and Malta are not Annex I Parties under the Kyoto Protocol, they have no EU AAUs. To prevent an adverse impact on the compliance with the Kyoto Protocol commitments of other Member States, the gateway prevents a net inflow of EUAs from Cyprus and Malta.

[55] Industrial sources in the other system could buy aviation allowances for compliance use and sell other units to industrial sources in the EU ETS. The effect is to make aviation allowances available to industrial sources in the EU ETS which circumvents the gateway.

6.4 Other Design Elements related to Harmonization of Linked Systems

6.4.1 Other design elements that should be assessed when considering linking include:

- mandatory versus voluntary systems
- tradable units accepted for compliance
- inclusion of direct or indirect emissions

6.4.2 **Mandatory vs. Voluntary Systems.** Linking a mandatory system with voluntary system could affect the environmental integrity of the mandatory system and risk competitive distortions. In order not to exclude links to voluntary systems but address the potentially adverse effects on the mandatory system, a requirement to demonstrate 'additionality' could be imposed. Opting into the mandatory system might also be a possible approach. It is noted that the EU ETS legislation only allows for linking with other mandatory systems.

6.4.3 **Tradable Units Accepted for Compliance.** When linking it will also be necessary to identify the types of units that could be used for compliance purposes. For example, one issue will be to establish the role (if any) AAUs might play in the linking of schemes. AAUs are a creation of international agreement, and their credibility depends upon all countries that are granted AAUs taking on stringent requirements in the same system. Beyond 2012 there is no certainty about the continued use of AAUs; international aviation emissions are not presently covered by AAUs. The national and regional systems outlined in sections 4.1 and 4.2 are company-based system whose operation is independent of external events, and banked tradable units are in most systems guaranteed to remain valid. It would therefore be possible to link scheme(s) involving aviation without any AAU transfers though there would be a challenge to establish a robust, transparent and credible international accounting system going forward.

6.4.4 **Direct or Indirect Emissions.** Emissions can be controlled directly at source or indirectly at the level of end-users. Linking two systems with different approaches can be technically complex.

6.4.5 Other provisions that do not create environmental risks and are rarely politically sensitive but may influence the ability to link include the **gases covered**, treatment of **new entrants**, and treatment of **closures**. The **registries** that track holdings of tradable units do not need to be compatible. The trading systems can be linked without an electronic link between the registries, through a transaction log that connects the registries electronically is desirable. Although harmonization is not necessary, the greater the similarity of these provisions the easier it will be to establish a link.

6.5 Maintaining Compatibility Over Time

6.5.1 Systems that establish a bilateral link must maintain their compatibility over time. To do this (as outlined in section 5.4) linked systems will require:

- A process for agreeing on revisions to the requirements of each system, such as regular meeting of administrators and the implementation of agreed revisions at specified intervals (e.g., every three or five years).

- A mechanism to provide assurance of the environmental effectiveness of each system, such as external verification of the compliance assessment performed by each system.
- A procedure enabling either system to terminate the linking agreement with reasonable notice.[56]

6.5.2 And finally, with linked systems there is an incentive for one or both systems (depending on whether the link is unilateral or bilateral) to adjust its emissions constraint (cap) so that it will be a net exporter of tradable units. To address this concern, the rules and procedure for adjusting the emissions constraint of each system is of particular importance when considering linking.

[56] For more discussion on maintaining compatibility, see Haites and Wang, 2008.

REFERENCES

Aust, A., 2007. *Modern Treaty Law and Practice*, 2nd ed. Cambridge University Press, Cambridge.

Australia, Commonwealth of, 2008. *Green Paper: Carbon Pollution Reduction Scheme*, 16 July 2008, Canberra, Australia [available at: http://www.climatechange.gov.au/publications/cprs/green-paper/cprs-greenpaper.aspx].

Australia, Commonwealth of, 2008. *White Paper: Carbon Pollution Reduction Scheme, Australia's Low Pollution Future,* December 2008, Canberra, Australia [available at: http://www.climatechange.gov.au/publications/cprs/white-paper/cprs-whitepaper.aspx].

Baron, R., and Bygrave, S., 2002. Towards International Emissions Trading: Design Implications for Linkages. Organisation for Economic Co-operation and Development (OECD) and International Energy Agency (IEA), Paris, France.

Canada, 2008. *Regulatory Framework for Industrial Greenhouse Gas Emissions*. March 2008, Ottawa, Canada [available at: http://www.ec.gc.ca/doc/virage-corner/2008-03/pdf/541_eng.pdf].

Chicago Climate Exchange (CCX), 2006. Chicago Climate Exchange and Baxter Healthcare Corporation Execute First Transaction Linking Greenhouse Gas Emission Trading Schemes in Europe and North America. CCX, Chicago, Il [available at: http://www.theccx.com/news/press/release_20060504_EUETS.pdf].

Edenhofer, O., Flachsland, C., and Marschinski, R., 2007. Towards a Global CO_2 Market: An Economic Analysis. Potsdam Institute for Climate Impact Research, Potsdam, Germany.

European Commission, 2007. *Emissions Trading: Commission Announces Linkage of EU ETS with Norway, Iceland and Liechtenstein.* Press Release IP/07/1617, 26 October 2007. Brussels, Belgium.

European Union, 2009. Directive of the European Parliament and of the Council amending Directive 2003/87/EC so as to improve and extend the greenhouse gas emission allowance trading scheme of the Community. Brussels, 26 March 2009 [available at: http://register.consilium.europa.eu/pdf/en/08/st03/st03737.en08.pdf].

European Union, 2004. *Directive 2004/101/EC of the European Parliament and of the Council of 27 October 2004 amending Directive 2003/87/EC establishing a scheme for greenhouse gas emission allowance trading within the Community, in respect of the Kyoto Protocol's project mechanisms*. Official Journal of the European Union, 13 November 2004, L 338/18-23. Brussels, Belgium.

European Union, 2003. Directive 2003/87/EC of the European Parliament and of the Council of 13 October 2003 establishing a scheme for greenhouse gas emission allowance trading within the Community and amending Council Directive 96/61/EC. Official Journal of the European Union, 25 October 2003 available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2003:275:0032:0046:EN:PDF]

Fischer, C., 2003. "Combining Rate-based and Cap-and-trade Emissions Policies," *Climate Policy*, v. 3, Supplement 2, pp. 89-103.

Haites, E., 2003. Harmonisation Between National and International Tradeable Permit Schemes: CATEP Synthesis Paper. OECD, Paris, France.

Haites, E., and Mullins, F., 2001. Linking Domestic and Industry Greenhouse Gas Emission Trading Systems. EPRI, International Energy Agency (IEA) and International Emissions Trading Association (IETA), Paris, France.

Haites, E., and Wang, X., 2008. "Ensuring the Environmental Effectiveness of Linked Emissions Trading Schemes Over Time," *MITI-Adaptation and Mitigation Strategies for Global Change*, Special Issue on Linking Domestic Emissions Trading Schemes (in press).

Herzog, T., Baumert, K., and Pershing, J., 2006. Target: Intensity. An Analysis of Greenhouse Gas Intensity Targets, World Resources Institute, Washington, D.C., November.

International Civil Aviation Organization (ICAO), 2007. Guidance on Emissions Trading for Aviation. Committee on Aviation Environmental Protection (CAEP), CAEP7-IP/20.

International Carbon Action Partnership (ICAP), 2007. *Political Declaration*. 29 October 2007, Lisbon, Portugal [available at: http://www.icapcarbonaction.com/index.php?option=com_content&view=article&id=12&Itemid=4&lang=en].

Jaffe, J. and Stavins, R., 2007. Linking Tradable Permit Systems for Greenhouse Gas Emissions: Opportunities, Implications, and Challenges, International Emissions Trading Association (IETA) and Electric Power Research Institute (EPRI), Geneva, Switzerland.

Lee, David S. and David W. Fahey, Piers M. Forster, Peter J.Newton, Ron C.N. Wit, Ling L. Lim, Bethan Owen and Robert Sausen: *Aviation and Global climate change in the 21st century.* Accepted publication in Atmospheric Environment, April 2009.

Mace, M.J., Millar, I., Schwarte, C., Anderson, J., Broekhoff, D., Bradley, R., Bowyer, C., Heilmayr, R., 2008. *Analysis of the Legal and Organisational Issues Arising in Linking the EU Emissions Trading Scheme to other Existing and Emerging Emissions Trading Schemes*, FIELD/IEEP/WRI, London, United Kingdom.

Marchinski, R., 2008. "Efficiency of Emissions Trading between Systems with Absolute and Intensity Targets," available at: http://www.pik-potsdam.de/members/robert/eaere08marchinski

Mehling, Michael and Erik Haites 2009: "Mechanisms for linking emissions trading schemes". *Climate Policy*, Vol. 9, No. 2, 169-184.

New Zealand, Government of, 2007. The Framework for a New Zealand Emissions Trading Scheme, Ministry for the Environment and The Treasury, Wellington, New Zealand, September 2007 [available at: http://www.mfe.govt.nz/publications/climate/framework-emissions-trading-scheme-sep07/].

New Zealand, Parliament of, 2008. Climate Change (Emissions Trading and Renewable Preference) Bill, as reported from the Finance and Expenditure Committee, 11 June 2008 [available at: http://www.legislation.govt.nz/bill/government/2007/0187/15.0/DLM1130932.html].

Regional Greenhouse Gas Initiative (RGGI), 2006. *Regional Greenhouse Gas Initiative Model Rule*, 15 August 2006 [available at: http://www.rggi.org/docs/model_rule_8_15_06.pdf].

Schule, Ralf and Wolfgang Sterk. "Options and Implications of Linking the EU ETS with other Emissions Trading Schemes." Submitted by the Wuppertal Institut to the European Parliament, March 2008. Contract Ref. IP/A/CLIM/NT/2007-18. Available at: http://www.europarl.europa.eu/activities/committees/studies/download.do?file=19802

Sterk, W., Braun, M., Haug, C., Korytarova, K. and Scholten, A., 2006. Ready to Link Up? Implications of Design Differences for Linking Emissions Trading Schemes, Jet-Set Working Paper I/06. Wuppertal Institute, Wuppertal, Germany.

Springer, U., Oleschak, R., Suter, S., Forrister, D., and Youngman, R., 2006. Linking Domestic Emissions Trading Schemes to the EU ETS, TETRIS Deliverable. Ecoplan, Berne, Switzerland.

Swiss Federal Council, 2005. *Verordnung über die Anrechnung der im Ausland erzielten Emissionsverminderungen* (CO_2-Anrechnungsverordnung), 22 June 2005 [available at: http://www.admin.ch/ch/d/sr/6/641.711.1.de.pdf].

Switzeralnd, 2008. *Startschuss zum Emissionshandel in der Schweiz*. Bundesamt für Umwelt, 11 June 2008, Berne, Switzerland[available at: http://www.bafu.admin.ch/dokumentation/medieninformation/00962/index.html?lang=de&msg-id=19266].

GLOSSARY

The terms contained herein are intended to clarify concepts as used in this document.

Accountable entity
The entity in a cap and trade emissions trading system that is responsible for measuring and reporting actual emissions and for submitting sufficient allowances to cover those emissions.

Additionality
To avoid giving credits for greenhouse gas emission reductions that would have happened anyway, eligibility criteria have been developed to determine if the reductions are 'additional' – that is, are more than would have occurred in the absence of the project ('environmental additionality') or in the absence of the incentive from the CDM ('project additionality').

Allocation
The initial distribution of allowances to accountable entities for a compliance period. This allocation could for example be based on historical emissions or a performance standard and level of production and could be made 'gratis' or through an auction process.

Allowance (emission allowance)
An allowance is a tradable emission permit that can be used for compliance purposes in a cap and trade system. Each allowance allows the holder to emit a specific quantity of a pollutant (e.g., one tonne of CO2) one time.

Allowance life
The allowance life is the period during which an allowance can be used for compliance purposes.

Annex B Parties or Countries
Group of industrialized countries and economies in transition listed in Annex B of the Kyoto Protocol that have commitments to limit or reduce their greenhouse gas emissions over the 2008-2012 period.

Annex I Parties or Countries
Group of industrialised countries and economies in transition included in Annex I to the United Nations Framework Convention on Climate Change (UNFCCC) that committed individually or jointly to returning to their 1990 levels of greenhouse gas emissions by the year 2000.

Assigned Amount Units (AAUs)
Emission targets for industrialized country Parties to the Kyoto Protocol are expressed as levels of allowed emissions, or "assigned amounts" for the 2008-2012 commitment period. Such assigned amounts are denominated in tonnes of CO2 equivalent emissions (CO_2e).

Auctioning
The distribution of allowance - either the initial distribution or from a set-aside, this is achieved through an auction in which system participants bid for the right to purchase allowances. Different auction models could be used. Auctions often complement other forms of allowance allocation.

Aviation bunker fuels
The international share of fuel sold to aircraft.

Banking
A banking provision permits allowances issued for one compliance period to be saved for use during a subsequent compliance period.

Baseline
A reference level of emissions. A baseline can be used for example to calculate the total quantity of allowances to be distributed under a cap-and-trade scheme or the quantity of credits generated under a baseline-and-credit (emission intensity) system. A baseline also sets the level of emissions that would occur without policy intervention in an offset program.

Baseline and credit (emissions intensity) system
An emissions trading system that establishes an emissions performance standard and allows regulated participants to generate tradable credits (or "emission performance credits/allowances") by reducing their emissions intensity below that standard. Regulated participants that remain with an emissions intensity above the standard would need to submit credits to the regulating authority.

Benchmarking
A reference level, such as emission per unit of output, that can be part of the formula for the free allocation of allowances under a cap and trade system or that can define the target in an emission intensity system.

Borrowing
A borrowing provision permits an accountable entity to use allowances for a future period to achieve compliance in the current period.

Buyer
A legally recognised entity (individual, corporation, not-for-profit organisation or government) that acquires allowances or other compliance units from another legally recognised entity (the seller) through a purchase, lease, trade or other means of transfer.

Bilateral link
A bilateral link is established if the administrators of two emission trading systems agree to accept allowances issued by the other system for compliance purposes.

Cap and trade emissions trading system
A Cap and Trade system allows for the trading of emission allowances that are limited or 'capped' in quantity by a regulatory authority. Before each compliance period, the regulatory authority distributes the allowances through a free allocation, sale, and/or auction. At the end of the compliance period each accountable entity must surrender sufficient allowances to cover its actual emissions during the period. The trading of allowances promotes cost-efficient emission reductions, as entities that can reduce emissions at lower cost have the incentive to pursue these emission reductions and to then sell their surplus allowances to entities that face higher emission reduction costs.

Carbon Leakage
The indirect effect of emission reduction policies or activities that lead to a rise in carbon emissions elsewhere (e.g., fossil fuel substitution leads to a decline in the price of fossil fuels and a rise in their use and a rise in carbon emissions elsewhere).

Certified Emission Reductions (CERs)
A compliance unit under the Kyoto Protocol issued for emission reductions achieved from project activities in non-Annex I Parties that meet the requirements of the Clean Development Mechanism (CDM). One CER is equal to one metric tonne of CO_2 equivalent.

Cirrus cloud
A type of cloud composed of ice crystals and shaped like hair like filaments. May be partly induced by aviation.

Clean Development Mechanism (CDM)
A mechanism established by the Kyoto Protocol that enables emission reduction projects in non-Annex I Parties to earn CERs that can be sold to entities in Annex I Parties for compliance with their emissions limitation or reduction commitments under the Kyoto Protocol.

Climate change
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Closed emissions trading
An emissions trading scheme that is designed to limit or reduce emissions within the boundaries of the scheme itself and thus does not allow for allowances or credits from outside the scheme to be used for compliance purposes.

Contrails
The condensation trail left behind jet aircraft. Contrails only form when hot humid air from jet exhaust mixes with ambient air of low vapour pressure temperature.

Credit or offset credit
In this report the term 'credit' or 'offset credit' is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Distribution
The allocation of allowances among accountable entities in a cap and trade system.

Domestic aviation emissions
Emissions from civil domestic passenger and freight traffic (commercial, private, agriculture, etc.) that departs and arrives in the same country including take-offs and landings for these flight stages.

Emissions intensity target
An emissions target defined in terms of emissions per unit of output.

Emissions trading
Emissions trading is a market-based tool that provides entities the flexibility to select cost-effective solutions to achieve their environmental targets. With emissions trading, entities can meet these targets either by reducing their own emissions or by securing through the market compliance units that take account of emission reductions achieved elsewhere.

Gateway
Instrument created to regulate the net flow of allowances between different groups of buyers and sellers.

Greenhouse gas
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent but very powerful greenhouse gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Greenhouse gas reduction or emissions reduction
A reduction in emissions intended to slow down the process of global warming and climate change. Greenhouse gas reductions are often measured in tonnes of carbon-dioxide-equivalent (CO_2e), which is calculated according to the GWP of a gas.

Indirect link
A system that establishes a unilateral or bilateral link with another system also establishes an indirect link with any other system to which the partner system is linked. An indirect link occurs without any formal or informal agreement between systems.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

Joint Implementation (JI)
JI is a flexible mechanism established by Article 6 of the Kyoto Protocol for project-based emission reduction activities in Annex B countries. Emission reductions from JI projects earn ERUs.

Kyoto Protocol
An international agreement reached in Kyoto in 1997 that is linked to the UNFCCC and inscribes, among other things, the emission limitation and reduction commitments made by developed countries for the 2008-2012 First Commitment Period.

Kyoto Unit
A unit, representing one tonne of carbon dioxide equivalent emissions, that an Annex B Party to the Kyoto Protocol can surrender to meet its limitation or reduction commitment under the Kyoto Protocol. These units are tradable between Kyoto Parties and include Assigned Amount Units (AAUs), Certified Emission Reductions (CERs), Emission Reduction Units (ERUs), and Removal Units (RMUs). In addition, under the second phase of the EU emissions trading scheme, EU allowances are specific Kyoto units which have been designated as being valid for trading under the scheme. Transactions in EU allowances are therefore recorded automatically as transactions under the Kyoto Protocol.

Leakage
The indirect effect of emission reduction policies or activities that lead to a rise in emissions elsewhere (e.g., fossil fuel substitution leads to a decline in the price of fossil fuels and a rise in their use elsewhere).

Multilateral link
A multilateral link is established when more than two systems agree to accept allowances issued by the other system(s) for compliance purposes.

Offset or offset credit
In this report the term 'offset' or 'offset credit' is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Offsetting
In this report offsetting is the activity of "cancelling out" or "neutralising" emissions from a sector like aviation using offset credits – compensating emission reductions created in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

Open emissions trading
An emissions trading system where allowances or credits from outside the scheme can be used for achieving compliance with obligations under the scheme.

Removal Units (RMUs)
A tradable unit that will be issued by the UNFCCC to an Annex B Party for CO_2 removals from the atmosphere achieved from specified sequestration activities during the first commitment period of the Kyoto Protocol.

Retirement
The permanent surrender of offset credits (or allowances) to achieve compliance with a regulatory or voluntary obligation or a country's international greenhouse gas commitment.

Seller
A legally recognised entity (individual, corporation, not-for-profit organisation, government, etc.) that transfers allowances or credits to another legally recognised entity via a sale, lease or trade in return for a monetary or other consideration.

Surrender of allowances/credits
The submission of emission allowances/credits by an accountable entity to fulfill its obligations under an emissions trading scheme.

Tradable unit
A generic term for compliance units that can be traded either domestically or internationally, including allowances from a cap-and-trade system, credits from a baseline-and-credit scheme, and offset credits created from either domestic or regional trading regimes or through the Kyoto flexibility mechanisms (from Clean Development Mechanism and Joint Implementation projects).

Unilateral link
A unilateral link between two emissions trading systems occurs when the administrator of one system agrees to accept allowances issued by the other system for compliance purposes. This acceptance of units is “one-way”.

United Nations Framework Convention on Climate Change (UNFCCC)
The UN Convention on Climate Change has been ratified by 192 countries and it sets an overall framework for intergovernmental efforts to tackle the challenge of climate change. Under the Convention, governments share information on greenhouse gas emissions, national policies and best practices, commit to GHG limitation/reduction activities/targets, and provide financial and technical support for the adaptation and mitigation activities of other countries.

Verification
Verification provides independent assurance that the emissions quantification and reporting have been accurately completed. The ‘level of assurance’ provided depends on the system requirements. In most systems the verifiers must be accredited by a standard setting organization.

Voluntary action or commitment
This is an action or commitment undertaken by an entity that reduces greenhouse gas emissions in the absence of any requirements to undertake such reductions.

— — — — — — — —

APPENDIX C

SCOPING STUDY ON THE APPLICATION OF EMISSION TRADING AND OFFSETS FOR LOCAL AIR QUALITY IN AVIATION

ICAO COUNCIL'S COMMITTEE ON AVIATION ENVIRONMENTAL PROTECTION

MARKET BASED MEASURES TASK FORCE

16 December 2009

TABLE OF CONTENTS

Executive Summary

This report explores the scope for the application of emissions trading and offsetting to the mitigation of airport local air quality (LAQ).

The report starts by outlining airport issues including locally regulated requirements, relevant emissions species and airport sources and assessment of compliance with regulations. An airport LAQ management framework might be established to address a non-compliance issue and market-based measures, including emissions trading and offsetting might be incorporated.

Establishing an emissions trading scheme (ETS) requires defining its scope (sources included and geographic coverage), determining a cap on emissions, as well as the allocation of allowances and on-going operation of the scheme.

Offsetting is a further option that can be permitted. Offset credits are generated by projects which reduce emissions and would not have otherwise been implemented. Parties in an ETS can buy offset credits in partial fulfilment of their ETS obligations.

The report provides a range of examples of ETS and offsetting implementation for local air quality situations, only one of which covered an airport. The lessons that were learned from these are discussed, and a set of principles for new schemes is recommended.

In closing, specific issues that ETS and offsetting present for airport LAQ are provided.

1. INTRODUCTION

1.1 Background

In its 7th meeting the Committee on Aviation Environment Protection (CAEP) tasked the Market-Based Measures Task Force (MBMTF) to conduct a "scoping study into the potential for the use of emissions trading for LAQ" (local air quality).[1,2]

1.2 Outline

This report explores the scope of emissions trading and offsetting to mitigate airport local air quality (LAQ). The report first provides an overview and definition of airport LAQ issues and potential mitigation measures, and then details the possible application of emissions trading and offsetting in existing airport LAQ management frameworks. This leads on to separate in-depth consideration of the application of emissions trading and offsetting within airport LAQ management frameworks, including conceptual and theoretical elements that broaden the discussion beyond existing experience. The report concludes by drawing a broad way forward intended to inform the ICAO-CAEP on the potential measures that could be applied in the areas of emission trading and offsetting for ameliorating LAQ issues at and surrounding airports.

This report recognises that "local" air quality may be defined in different ways and addressed at different levels. It can refer to the air quality at a particular point location (an airport in the context of this report) or a wider area (such as an airport and its surrounding area) or it may extend to the regional or national scale (a political boundary for example). As this study was established primarily to consider the use of emissions trading and offsetting to address LAQ at airports and their immediate surroundings, this will be the primary focus of the report, though the role an airport might play in a broader, regional approach to addressing LAQ will also be considered.

The focus of this report is on ambient air quality – that is, on the total effect of the range of sources of LAQ emissions within a particular area, rather than on emissions from any particular source.

Section 1 of this report introduces the concepts of emissions trading and offsetting, and outlines some aspects of policies to address LAQ that are explicitly excluded from the discussion. Section 2 provides a background to the issue of LAQ at and around airports; explains the different geographic scales at which an authority might choose to address LAQ; and defines the main elements of emissions trading and offsetting systems. Section 3 provides a summary of desk-based research on the real-world application of emissions trading and offsetting for airport LAQ management. Section 4 summarises the lessons learnt from the examples identified in Section Three. Section 5 examines specific issues that need to be considered for the application of emissions trading and offsetting to address LAQ at airports.

[1] (task M 0.3, Appendix A to the CAEP7 report, February 2007)

[2] During its preparatory work, the sub-group of the MBMTF in charge of this task came to the conclusion that an extension of the scope of the study to include offsetting for LAQ purposes was appropriate. There were two reasons for this: a) the main issues concerning the application of offsetting to LAQ emissions are similar to those concerning the application of emissions trading to LAQ emissions; and b) it was considered desirable to consider the creation of LAQ allowances in aviation that might be used to offset emissions as part of an emissions trading mechanism associated with any airport LAQ management framework. This extension was agreed to by the CAEP Steering Group in September 2008.

1.3 **Emissions Trading**

Emissions trading is a means of harnessing market forces to create incentives for economic agents to discover and implement cost-effective approaches to complying with environmental targets. The basic argument for using emissions trading as an environmental policy tool relates to the potential costs saving a trading system can generate relative to a conventional command and control approach. In particular, when regulated entities are allowed to buy and sell emission instruments, market forces can create an incentive for firms with relatively low-cost emission reduction options to reduce their emissions by more than needed to satisfy their regulatory requirements. These entities are then able to sell surplus emission instruments to other regulated firms that are faced with relatively high-cost emission control options. The opportunity to sell surplus emission instruments can create incentives for cost-effective compliance with environmental targets. As a result, incorporating an emissions trading system into an environmental policy can mean that the same level of environmental protection can be achieved at a lower overall cost.

There are two different approaches to emissions trading: "cap and trade", which involves the application of an absolute emissions limit (cap); and "baseline and credit", which involves an emissions intensity approach - the reduction of emissions per unit of output. Although the latter approach provides flexibility for changes in output or turnover (in the case of an airport, if its use increased or decreased) this report focuses on the 'emissions cap' (allowance-based) approach, examples of which are more widespread and better established. Emissions trading encourages the implementation of cost-effective emission reduction strategies and provides flexibility to emitters in the way they manage their emissions obligations. With emissions trading, emitters can meet established emission limits or goals by:

- reducing emissions from their own sources covered by the scheme;
- purchasing allowances from another participant within the scheme;
- purchasing allowances from participants in a linked scheme; or
- purchasing allowances from emitters not subject to the scheme (offsetting) where that is permitted (see 3.3 "concepts of offsetting for LAQ management").

1.4 **Offsetting**

In general terms, an offset is a "compensating equivalent". As an activity, offsetting is the "cancelling out" or "neutralising" of emissions from a sector like aviation with emissions reductions in a different activity or location. The term 'offset' has been used interchangeably as both an activity to compensate for emissions and as the product of this activity. For the purposes of this paper, 'offsetting' will be used to describe the actions undertaken to compensate for emissions. An 'offset' (as a product) is a credit or unit derived from the reduction of emissions. An offset therefore represents a unit of measurement that quantifies the action of offsetting; e.g. an offset could equate to one kilogram of NOx emission reduction. These credits can be tradable units. To avoid confusion when referring to the measurement that has been derived from an offsetting activity, the term "offset credit" or "credit" will be used in the paper.

Offsetting must also be distinguished from emission trading. If for example a regulated emitter acquires emission credits or emission allowances from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to as emission trading.

A more detailed explanation of both emissions trading and offsetting, and of the distinction between them, is provided in Section 2.

In terms of emission sources, this report assumes that a framework to improve airport LAQ will include both aircraft and non-aircraft sources in order to provide the scope for emissions reductions around the airport. In turn, this is based on the assumption that although aircraft are usually the dominant source of LAQ emissions at airports, they are unlikely to represent the simplest and lowest-cost source of emissions abatement.

For the purposes of this report, an emissions "allowance" (used in emissions trading) and emissions "credit" (used in offsetting) are defined as tradable units granting the holder permission to emit a specific quantity of pollution once (e.g. 1kg of NOX).

1.5 Specific exclusions of this report

It is important to note that this report focuses only on the application of emissions trading and offsetting as means to mitigate LAQ at and near airports. It does not seek to explore the genesis of LAQ problems nor the means by which emissions from individual sources could be mitigated. Neither does this report address technological or operational measures for the reduction of local emissions by the airlines or airports themselves. Although emissions trading and offsetting constitute market-based measures, other market-based measures such as emissions-based landing charges are not considered here. These issues and measures have been analysed by CAEP and detailed in the following documents:

- ICAO Doc 9884 "Guidance on Aircraft Emissions Charges Related to Local Air Quality". The most relevant part of this document is Chapter 3 which covers LAQ assessment, including reviewing standards and regulation, determining airport air quality, and assessing compliance.

- ICAO CAEP Doc 9889 "Airport Air Quality Guidance Manual" (preliminary unedited version 2007) covers issues related to the assessment of airport-related air quality that are either specifically within the remit of ICAO (such as aircraft main engine emissions) or where there is established understanding on other non-aircraft sources (such as aircraft handling, infrastructure and stationary sources, and ground vehicle traffic) that can contribute, to a greater or lesser extent, to air quality impacts. The document also addresses LAQ standards and regulations, emission inventories and the temporal and spatial distribution of emissions.

This report does not consider noise nor climate change impacts of aviation, although it is recognised that there can be trade-offs between improvements in local air quality and reductions in noise or greenhouse gases.

2. BACKGROUND AND DEFINITIONS

2.1 Airport Local Air Quality

2.1.1 Emission Species That Affect Airport Local Air Quality

Common emissions species considered in airport air quality assessments include oxides of nitrogen (NOx), hydrocarbons (HC), particulate matter (PM) and carbon monoxide (CO), though other pollutants such as sulphur oxides (SOx) are often assessed as well.

NO_x and HC are the main contributors to combustion-related local air pollution and precursors of ground level ozone, and for aircraft both are subject to international standards.[3] However, not all pollutants or their sources are regulated.

Of the primary air pollutants resulting from aircraft activities impacting upon airport LAQ, NOx emissions are formed most intensively during the high power phases of engine running, in particular for take-off. CO and HC are emitted primarily during low power phases of engine running, for example taxiing, as a result of incomplete fuel combustion. Engine emissions also include particulate matter (PM).

The application of trading and offsetting to the mitigation of LAQ issues is fundamentally more complex than their application for the reduction of GHG emissions. This is the case because the climate impacts associated with GHG emissions are global – that is, it does not matter where atmospheric inputs of CO_2 are made, whereas the impacts of NO_X, SO_X, HC, PM and CO emissions have their main impacts on local air quality.

2.1.2 Assessing and Defining Airport Local Air Quality

LAQ in and around an airport is usually quantified in terms of ambient pollutant concentrations. Ambient pollutant concentrations can be ascertained either by direct measurement using air sampling and analysing equipment, or by calculation (using airport activity data, emissions inventory, numerical dispersion models of emissions from each source and their interaction with the physical environment). Usually a combination of both is required.

ICAO Doc 9889 (Airport Air Quality Guidance Manual) covers issues related to the assessment of airport-related air quality and therefore these issues are not covered in any depth here. ICAO CAEP is developing dispersion modelling guidance and measuring guidance to include in this manual for CAEP/8 in 2010. More information on identifying relevant LAQ standards, regulations and ways of determining airport air quality can also be found in ICAO Doc 9884.

2.1.3 Airport Local Air Quality Emissions Sources

There are a great variety of LAQ emissions sources at an airport, however data compiled by the CAEP Modelling and Database Task Force (MODTF) shows that aircraft typically account for the majority (30-

---

[3] ICAO Annex 16 — Environmental Protection, Volume II — Aircraft Engine Emissions defines mandatory limits on NOx, CO and HC emissions for engine certification.

85% depending on species) of total airport emissions. Aircraft emissions with LAQ effects are considered in the ICAO CAEP Document 9884 (Guidance on Aircraft Emissions Charges Related to Local Air Quality) as "Aircraft emissions generated in the vicinity of an airport by aircraft either arriving or departing from that airport. The aircraft emissions include those generated from aircraft main engines either on the ground or in the air up to a level deemed to have a local effect, as defined by the jurisdiction where the emissions are released".

Generally the airport authority would be responsible for the emission sources it owns such as GSE (ground service equipment), airside vehicles, power generation and heating/cooling plants. At many airports, major airlines own and operate their own GSE. Some airport authorities might include within their area of responsibility emissions from public vehicles while on the airport property, parking garages, and staff travel to and from home.

The largest source of LAQ emissions at airports are aircraft during the landing and take off cycle (LTO), taxiing and aircraft auxiliary power units (APUs). While airlines are clearly the owners of these sources, airports can exert influence in respect of the management of these emissions. Providing fixed electrical ground power (FEGP) and pre-conditioned air (PCA) to aircraft at gates allows reduced APU usage. Holding aircraft at the gate until departure slots are ready and providing direct taxiways can reduce taxiing and queuing. Within an airport LAQ emissions trading scheme, it would be important to identify the party responsible for the surrender of allowances for aircraft emissions, and the manner in which variables such as taxiing and queuing periods, reduced thrust-take-off and continuous descent approach should be accounted for.

In deciding whether a particular source or source category should be included in a LAQ management framework, regulators may consider whether the source makes a significant contribution to overall emissions, any relevant legal limits for emissions levels, potential health problems associated with the emissions, and whether emissions from the source can be reliably measured and verified. As mentioned, ICAO Doc 9884 and 9889 can assist in this regard.

Privately-owned vehicles including cars and trucks are a major group of emissions sources that are not usually subject to regulation or emissions caps. While they might be included in an airport LAQ Management Framework as a source that an airport can influence, for example by the rate of parking fees, they would not be included in an airport LAQ ETS.

2.2 Establishing an Airport Local Air Quality Management Framework

A LAQ management framework can be defined according to a variety of different attributes. These could include geographic scope, pollutant species and concentration or the emissions sector(s) subject to management. This definition of an airport LAQ management framework will influence the scope and nature of any emissions trading and offsetting that is employed to help fulfil its objectives.

2.2.1 Defining an Airport Local Air Quality Management Framework by Geographic Coverage

I. Airport Boundary

One approach to defining an airport LAQ management framework is to use the boundary of the airport itself. This could include one or a number of emissions sectors or defined activities e.g., aircraft only or all sources (see 2.2.2).

However, this approach would introduce difficulties if not all emissions sources within the airport boundary (including private vehicles that moved into and out of the boundary) were covered by the framework. In such a case, emissions sources within the framework may achieve the desired goal though ambient emissions levels remain above required levels due to an increase in emissions levels from sources not subject to the framework.

Strict adherence to the airport property for defining a framework may not always be appropriate. For example, some airport activity may take place off the airport property but immediately adjacent to it (e.g. an aircraft maintenance hangar). Efforts to include such activities may be required even if the levels of emissions are negligible to ensure that emissions are not simply displaced to avoid counting.

II. **Airport and Surrounds**

Although "regional" LAQ frameworks are outside the scope of the core discussion in this paper, an airport LAQ framework could potentially be extended on a limited basis to cover a defined area surrounding an airport. This would enable the inclusion of "external" emission sectors and sources that might have been proven to have a direct and significant impact upon airport LAQ (for example a nearby power station or motorway). Particular local circumstances would influence the definition of the boundary to an "airport and surrounds" framework, including, for example, the existence of emission sources outside of the airport and prevailing wind conditions.

There are a range of potential scenarios for the definition of such a framework, from the inclusion of specific point emission sources outside of the airport boundary, to the defining of a "buffer" zone outside of the airport. Generally, through the inclusion of a greater number and quantity of emission sources, an "airport and surrounds" framework would provide for a greater degree of emissions trading and offsetting.

However, the extension of the geographic coverage of an airport LAQ framework beyond an airport property could result in problems of ensuring that LAQ at the airport itself is actually improved. Any trend for trading and offsetting to favour emission sources beyond the airport might impact upon the effectiveness of LAQ improvements at the airport itself. The effect of increasing distance of emission sources from an airport itself could be managed by assigning a greater "value" to trades and offsets according to their proximity to the airport in question.

Further considerations may include unwillingness of emitters external to and unrelated to an airport to participate in such an airport LAQ framework. Mandatory inclusion could raise objection. In addition, by enlarging the region in which emission reductions can take place, it is possible that emission "hot spots" may arise. The airport itself could become a "hot spot" if the majority of low cost emission reductions were outside the airport itself, which would confound the aims of the management framework.

Thus this paper assumes that any proposed market-based measures are designed to address a LAQ problem at, or in the immediate surroundings of, an airport. Broader, regional-scale LAQ management frameworks are not covered in this paper as they will likely comprise larger, overarching multi-sectoral initiatives in which airports could participate but would not have any element of control.

2.2.2 **Defining an Airport Local Air Quality Management Framework by Emission Source**

While the predominant source of emissions at an airport will usually be aircraft, an airport will also have a number of other emission sources, including aircraft maintenance and testing, ground support equipment, airport vehicles and other stationary sources such as boilers and power generation. This presents two principal options for the scope of a LAQ management framework – aircraft-only or all sources.

I. **Aircraft-only Sources**

This scenario assumes that only the aircraft operating from an airport are included within a LAQ framework and any associated emissions trading/offsetting mechanism. Various measures are available to aircraft operators to reduce emissions, relating primarily to operating practices and engine technologies. However not all of these measures will be within the direct control of the aircraft operator. In addition, the marginal abatement cost of these measures (that is the financial cost of achieving an additional unit reduction in emissions) tends to be high; and the range of marginal abatement costs between these measures tends to be low, thereby making trading less effective as a tool for reducing compliance cost.

Offsetting between aircraft operators might, in theory, be possible. However, in view of the limited opportunities for abatement and relatively high marginal abatement cost, it is unlikely that such offsetting would be feasible.

Given the limitations associated with this option, it will not be considered further within the scope of this paper.

II. **All Sources**

The incorporation of emission sectors other than aircraft enables greater flexibility and scope for emission reductions over an aircraft-only framework. The extent of the inclusion of such additional sources would be influenced also by the geographic coverage of the framework in question. For an "airport boundary" framework this would be restricted to emission sectors at the airport itself (for example airport power generation and ground based transport). If the geographic coverage of an airport LAQ management framework was set beyond the boundary of the airport, then the scope of the inclusion of sectors could be very wide ranging, depending on the location of roads, industrial plants and power generation etc near the airport.

2.2.3 **Defining an Airport Management Framework by Source Specification**

For the purposes of establishing an emission trading system (ETS) for LAQ, an alternative approach would be to draw up an explicit list of the sources that would be included in the scheme. This would avoid geographical or sectoral difficulties relating to sources not subject to the mandatory cap of the ETS (e.g. private vehicles), or mobile sources that cross into or out of the airport property or other potential ETS boundary.

From the outset, the ETS would clearly identify the emissions sources and the scope of the scheme. For example an LAQ ETS could include, *inter alia*, any of the following sources:

- a power or heat generation station, either owned by the airport or one located near the airport;

- aircraft during the LTO cycle (typically below 3000 ft) including start-up, APU and taxiing emissions;

- airside vehicles and ground service equipment;

- ground transportation vehicles including public transport and private vehicles while on the airport property;

- airport staff and tenant vehicles from point of origin to airport and return;

- construction and maintenance activities on the airport property.

2.3 Regulating Local Air Quality in the vicinity of airports

Regulations on this issue have two fundamentally different forms:

- Local Air Quality Regulations – Limits of acceptability in the form of concentrations of pollutant species at receptor locations.

- Emissions Limits – Limits placed on the emissions of individual sources such as annual mass of NOx for a power station or mass of NOx per operation of an aircraft.

LAQ is regulated in many states and regions, through a variety of different approaches. In many cases, regulations apply binding, state-wide limits on the ambient levels of different pollution species. These would apply equally to airports, cities and transport corridors. Location-specific regulations (for example at an airport or in the region within which an airport is located) are also possible. In most cases, it is the legal requirement to meet LAQ regulations that might prompt the introduction of LAQ measures at, or in the region surrounding, an airport.

Regulations of emissions apply to the individual types of sources. Examples include the following:

- Regulations on emissions from power generators or power stations.

- ICAO standards on CO, HC and NOx emissions from aircraft engines, which must be met before a new engine can be certified.

- State and national regulations on emissions from cars and trucks.

In general, an overarching LAQ regulatory requirement will be behind the setting up of a LAQ framework. An airport authority may establish a LAQ Management Framework to determine how best to address an issue of non-compliance local LAQ requirements. Alternatively a regulating authority might set up a regional LAQ Management Framework and include the airport within it.

Responsibility for compliance with the LAQ requirement might fall either :

- the “emitters” themselves (e.g. airline operators and fixed-based emitters); or

- those who administer and operate airports (e.g. airport authorities).

For example, the state might consider all of the emissions directly associated with the airport, no matter what the source, and set a total cap on the emissions. If the state could regulate the airport (with the consequences of non-compliance well defined), the airport administrator would have to develop a plan to reduce emissions to levels no greater than the cap. In the US, for example, under the Clean Air Act (1990), state power is available to impose emissions caps, although this power is limited to "new or modified" airports. However, there may not always be a source of authority for states to impose emissions caps on airports and in this situation states and airport authorities could instead formulate "voluntary" and "cooperative" agreements.

2.4 Application of Market Based Measures by Airport Local Air Quality Management Frameworks

The means to improve LAQ at airports will ultimately entail the application of the process or technology improvements previously outlined. Market-based measures (trading and offsetting) provide the incentive (where emission limits are challenging) to implement the lowest cost improvements. In other words, market based measures are simply a tool available to authorities to cost effectively achieve their LAQ objectives.

Market-based measures to achieve an LAQ goal can be used an alternative to a regulating authority applying emissions limits to individual sources. This should allow the necessary emissions reductions to be achieved in the most cost-effective manner.

2.5 Emissions Trading as a Mechanism for Airport Local Air Quality Management Frameworks

2.5.1 'Cap and Trade' Systems

Emissions trading generally requires regulation to require emissions declared by participants be verified and allowances equal to these emissions be surrendered. Emissions trading would generally form an integral part of a regulated overarching framework (in the context of this paper an airport LAQ management framework). As noted in section 1.2, this report focuses on the "cap and trade" approach, whereby a regulatory authority sets a cap on total emissions, issues allowances equal to this cap and then allows participants to purchase allowances from other participants in the system to use for compliance purposes. This may apply to a group of regulated emitters or a single body (such as an airport operator) over a set period. The regulator will issue allowances equal to the cap. Regulated emitters are required to possess and then surrender allowances equal to the amount of their emissions over a period. If an emitter has excess allowances, these can be sold to an emitter that requires more. Conversely, if an emitter has allowances less than their total expected emissions for the period, they must purchase additional allowances. The benefits of such a trading system are the certainty of not exceeding an absolute cap on total emissions and a mechanism that encourages use of the most cost effective emissions reductions.

As already detailed in section 1.2., a further type of emissions trading mechanism exists in the form of a 'baseline and credit' approach. Although this report focuses on 'cap and trade', it is noted that a baseline and credit system establishes an emissions performance standard and allows regulated participants to generate "emission performance allowances" by reducing their emissions intensity below that standard. These allowances can be traded with anyone that requires them. Such frameworks are subject to the criticism that there is no binding cap on emissions. However, because emitters' targets (implicit allocation) are defined in proportion to their level of production, emitters receive a more stable financial incentive to reduce their emission intensity, independent of their level of production. This incentive to reduce emissions per unit of output is retained even when going though an economic recession thereby preserving the environmental benefit of the scheme.

2.5.2 Setting a Local Air Quality Emissions Cap

The target level for emissions of any species of pollutant will constitute the overall emissions cap. A cap may keep total emissions at pre-existing levels or introduce a reduction in total emissions according to the nature of the target. The cap would be pre-determined based on the environmental benefit / improvement in LAQ sought, but economics, technical feasibility and potential effects on other environmental problems such as noise and greenhouse gas emissions may also need to be taken into account. Emission caps may be fixed or set to become more stringent over time. Emissions from any individual source within the framework may vary as long as the overall cap is not exceeded. The stringency of the cap is a key factor influencing the market price of emission allowances.

2.5.3 Defining & Allocating Emission Allowances

The setting of an emissions cap enables the definition of emission allowances; the tradable unit or "currency" that can be used for compliance purposes in an airport LAQ management framework. An allowance grants the holder permission to emit a specific quantity of pollution once (e.g. one kilogram of NOX). The total number of allowances available from any emissions trading mechanism equals the overall emissions cap. The allocation process to distribute allowances to emitters for each compliance period could include:

a) grandfathering, in which allowances are distributed according to historic levels of emissions, output or both;

b) auctioning, in which emitters bid to purchase allowances; or

c) output or performance-based allocations, based on a common emissions factor multiplied by the current activity level.

It is also possible to use a combination of allocation methods such as grandfathering and auctioning. For example, a new emissions trading mechanism might allocate a proportion of the allowances for free based on historic emissions and make the remainder available through an auction. The proportion distributed for free can be set to decrease over time.

Mechanisms such as flexible timing – the borrowing or banking of allowances, can be applied to the use of emission allowances. Borrowing allows a permit holder to use allowances earlier than their "vintage year" (the compliance period for which the allowances have been defined), while banking allows a user to store allowances for use in future use. These issues are not considered in detail in this report[4].

2.5.4 Voluntary or Mandatory Emissions Trading

As outlined in the section on scope, it is assumed that participation within an emissions trading mechanism (as part of an airport LAQ framework) will be mandatory. Mandatory participation enables the regulation of targeted emitters to ensure the emission target is achieved. Trading helps to reach this target at a lower cost. The setting of the cap is a key design decision.

[4] For further information, see the MBMTF M.02 report: International Civil Aviation Organization (forthcoming), Scoping Study of Issues Related to Linking Open Emissions Trading Systems Involving International Aviation, Committee on Aviation Environmental Protection (CAEP).

It is possible to allow any other non-targeted emitter to voluntarily participate within an airport LAQ framework (and as such any associated emissions trading mechanism) in order to reduce the net impact of their activities. If the cost of reducing emissions is high, the volume of voluntary reductions would tend to be small. However, it may always be worth considering voluntary participation for the limited LAQ benefit, but also to increase the scope of the trading market and provide a flexible means to achieve emissions reductions in future and as a means to obtain practical experience of trading.

2.6 Offsetting as a mechanism for Airport Local Air Quality Management Frameworks

As with emissions trading, the application of emissions offsetting will depend on the definition of an airport LAQ framework. That definition will establish which actions are eligible for the generation of offset credits to be use in offsetting.

2.6.1 Distinction between Emissions Trading and Offsetting

As detailed in section 3 of the MBMTF M.04 Offsetting report[5], the activity of emissions trading occurs only when both the seller and buyer of emissions allowances operate within the same system or in formally linked systems. If the generation of emission reductions occurs outside these systems, but the reductions (quantified as offset credits) are accepted for achieving compliance within the system, the activity is called offsetting. Offset credits need to meet the requirements of the regulator, as set out in the requirements for achieving compliance with the regulator obligation.

2.6.2 How Offsetting Works

Offsetting is the act by companies or individuals of compensating for their emissions by, for example, financing (through the purchase of offset credits) the reduction of an equivalent amount of emissions elsewhere. Offsetting can be purely voluntary when the emitter is not subject to any regulated limit on its emissions, or complementary to the normal trading of allowances as part of a regulated emissions trading scheme. The concept of offsetting has been used in the context of reducing greenhouse gas (GHG) emissions to address climate change, but the concept can also be applied to LAQ management.

Regulated emitters in an emissions trading mechanism as part of an airport LAQ management framework may be permitted to use emission reductions from a source not included within the scope of that LAQ management framework for compliance purposes[6]. For example, if an airport can no longer easily reduce the emissions from a source within an LAQ framework, it might be permitted to use the reduction of another source outside the framework. This might include the emission reductions achieved when the airport funds the introduction of lower emission buses transporting passengers to the airport. Such an action would generate an emission reduction (referred to as an 'offset credit' or a 'credit') recognised by the framework regulatory authority as equivalent to an allowance within the framework mechanism. As with allowances, an offset credit grants the holder permission to emit a specific quantity of pollution once (or to surrender that credit to "offset" their emissions). A limit could be set on the volume of offset credits that could be used for compliance. Depending on local circumstances, for example the size of the LAQ management framework, or the characteristics of the pollutant being managed, the opportunities for offsetting may be limited.

[5] International Civil Aviation Organization (forthcoming), Offsetting Emissions from the Aviation Sector, Committee on Aviation Environmental Protection (CAEP).

[6] If the source is covered by another linked ETS then the activity would be 'emissions trading' rather than 'offsetting' See the MBMTF M.02 report: International Civil Aviation Organization (forthcoming), Scoping Study of Issues Related to Linking Open Emissions Trading Systems Involving International Aviation, Committee on Aviation Environmental Protection (CAEP).

Another application of offsetting would involve entities outside of the scope of a LAQ management framework acquiring and cancelling allowances from within the framework. This action has the effect of tightening the cap, thereby forcing emitters to further reduce their emissions. This kind of action has occurred with the EU ETS, however, it will not be considered further in this paper.

2.7 **Additionality**

For an offset credit to receive approval for use within a LAQ management framework, it must have environmental integrity. More specifically, an offset credit needs to demonstrate the generation of permanent, verifiable emission reduction that is additional to or beyond business-as-usual activities. The proof of 'additionality' is a fundamental part of the offsetting process, but it makes the mechanism more complex to operate than might initially be apparent. The concept of additionality remains one of the most widely and contentiously debated elements in the generation of acceptable offset credits, especially in relation to the project-based instruments of the Kyoto Protocol.

3. EXAMPLES OF THE APPLICATION OF EMISSIONS TRADING AND OFFSETTING TO LOCAL AIR QUALITY

This section contains a summary of information gathered from research on the application of emissions trading and offsetting for airport LAQ management that have been established to date in countries across the world.

Framework Title	Country	Date Commenced and Objective	Scope	Framework Details	Status	Comments – Results of Evaluations
U.S. Acid Rain Trading Program	U.S.	1995 - Reduce acid rain	Electricity generating plants – national coverage	National cap of 8 million tonnes. Tradable allowances equal to the cap are freely allocated based on heat input and historical output of each plant. Limited (2.8%) auctioning takes place. Banking of allowances permitted.	Active	Between 1989-1991 and 2006-2008 average ambient sulfate concentrations have decreased by 38 percent in the Mid-Atlantic, 44 percent in the Midwest, 43 percent in the Northeast, and 28 percent in the Southeast. More detailed information can be obtained from the US EPA.
Northeastern U.S. NOx Budget Trading Program	U.S.	2003 - 04 (Phase 3) - Reduction of regional tropospheric ozone (smog) through reduction of NOx emissions	12 States in NE U.S. Applies to electricity-generating facilities and industrial boilers of 15MW capacity or greater	Cap and trade system based on 1990 emission levels. Emission allowances allocated to units by relevant State. Banking of allowances permitted under controlled circumstances.	The NBP was replaced by the Clean Air Interstate Rule (CAIR) NO_x ozone season trading program, it went into effect May 1, 2009	The 2008 NOx Budget Trading Program Annual Report, covering 20 eastern states and the District of Columbia, shows the summertime NOx emissions from power plants and large industrial sources were down by 62 percent compared to year 2000 levels and 75 percent lower than in 1990. More detailed information can be obtained from the US EPA.

Framework Title	Country	Date Commenced and Objective	Scope	Framework Details	Status	Comments – Results of Evaluations
Los Angeles Air Basin RECLAIM Program	U.S.	1994 - Meet legal requirements to reduce NOx and SOx	South Coast Air Quality Management District governing the area surrounding Los Angeles, California. Multi-industry framework.	Cap and trade system	Active	Initial oversupply of allowances did not incentivise emission reductions until 2000/01 energy crisis when old, high-emitting equipment brought back into service, using up allowance allocations and brought available allowances into the market. Resultant high price and scarcity of emission allowances led to amendments to stabilise the market. More detailed information can be obtained from the US EPA.
Boston Logan Airport	U.S.	2001 - Maintain airport associated NO_x emissions at or below 1999 modelled levels	Boston Logan Airport	Cap and trade system based on 1999 emission levels. Use of NOx emission allowances in the event that NOx emissions exceed 1999 baseline.	Active	Currently, NO_x emissions remain below 1999 baseline (emissions in 2005 were approximately 600 tonnes/year less than 1999 levels, a 28% decrease). As such, there has been no trading of NO_x emission allowances Although there has been no need to trade NOx emission allowances, the framework has not actually defined the source of such emission allowances should they be required. Airlines have questioned the legality of the framework.

Framework Title	Country	Date Commenced and Objective	Scope	Framework Details	Status	Comments – Results of Evaluations
Ontario Emissions Trading Program (Ontario)	Canada	2001 – Not to exceed 39 kilotonnes of NOx by 2007. 2005 - Reduce emissions of NOx by 21% and emissions of SOx by 46% on 1990 baseline levels by 2015	Province of Ontario Electricity sector 7 Industrial Sectors	Cap and trade system	Active	Framework incorporates pollutant emissions both within and up-wind of Ontario, and as such permits the use of other (U.S. or other Canadian provinces) emission reduction credits from eligible emissions trading programs within a defined zone.
Slovakia SO_2 Trading Program	Slovakia	2002 - Reduce SO_2 emissions to achieve compliance with the Gothenburg Protocol	Slovakian emission sources exceeding 50MW output capacity (80% of Slovakian SO_2 emissions) Emissions targets set by district.	Cap and trade system. Banking of emission quotas is not permitted.	Active	In the first phase of the programme (2002-04), emissions quotas were higher than the baseline emissions. In the current phase (2006 onwards) total allowances have been set below the baseline emissions, and by 2010 the quotas will be reduced by 45%. Purchasing quotas is not permitted in regions non-compliant with ambient air quality norms, as such sources located in such regions have only one option to reduce their emissions.

Framework Title	Country	Date Commenced and Objective	Scope	Framework Details	Status	Comments – Results of Evaluations
Dutch NO_X Trading Program	Nether-lands	2005 - Comply with EU Directive on National Emissions Ceilings (NEC Directive) and reduce overall NO_X emissions from 490,000 tons in 1995 to 260,000 tons in 2010.	National	Based on 'relative caps' directly related to the 'activity level' of a facility. Allowances automatically determined by multiplying the Performance Standard Rate (PSR) by total fuel input or production of the facility.	Active	One of the reasons an ETS was implemented was because of the need to limit reduction costs. The use of PSR provides greater flexibility for participants to increase production as required. A uniform PSR would favour the more pro-active companies that have taken early action. An ETS based on PSRs is not able to guarantee emission reduction targets in absolute terms.
Chilean PM10 Emissions Trading Program (Santiago)	Sant-iago, Chile	1992 - Control of particulate matter (PM10) emissions	Santiago area - program covers large industrial sources of PM10 with exhaust gas flow rates greater than 1,000 m3/hour)	Emission-offsets trading program	Active	All large industrial sources have met the emission reduction goal. Although the targets to reduce PM10 were met, during the first three years of the program, no transactions were approved while the regulatory authority developed source and emission inventories. Subsequent to this there has been little market activity due to high transaction costs, uncertainty and low enforcement.

Framework Title	Country	Date Commenced and Objective	Scope	Framework Details	Status	Comments – Results of Evaluations
Chinese Pilot Emissions Trading Programs	China	1994 - Reduction of SO_2 emissions from electricity generators and industrial sources using emissions trading (pilot projects)	Experimental programme covering cities of Baotou, Kaiyuan, Liuzhou, Taiyuan, Pingdingshan and Guiyang.	Emissions trading programmes taking different forms, including: allowance transfers within an enterprise, environmental compensation fees to obtain additional emission rights, investments in non-point source pollution control to obtain additional emission rights; and allowance transfers from sources with surplus allowances to new or existing sources with insufficient allowances.	Assumed now inactive	Pilot programme; exact results unknown. Pilot frameworks identified "issues and barriers" that may apply in an airport context, including need to establish a legal authority (China had issued no explicit legal authorisation); need for uniform allocation method (flexibility in determining allocations was given to regions and districts); monitoring and verification (need for standardisation and continuous measurement), and; need to address co-ordination and compatibility with other policy instruments.

4. LESSONS LEARNED FROM EXISTING AND HISTORICAL LOCAL AIR QUALITY EMISSIONS TRADING AND OFFSETTING SCHEMES

4.1 Essential features for the application of emissions trading and offsetting in addressing airport LAQ

While there are relatively few examples of offsetting frameworks on which to base conclusions, the examples set out in Section 3 facilitate identification of necessary components and characteristics for the incorporation of emissions trading and offsetting in future airport LAQ management frameworks.

4.1.1 Responsibility and competence of regulators

In a voluntary airport LAQ management framework, each participating entity will have agreed to comply with the framework. However, in a mandatory framework, the implementing body must have responsibility for regulating all the sources covered by the framework. While many local or regional authorities have the competence to ensure compliance with national LAQ standards and regulations, they may not have the ability to directly regulate individual emissions sources. This is particularly true in the transport sector with regard to mobile sources.

Offsetting presents a slightly different set of issues. Offsetting must first have received approval by the regulator of any airport LAQ management framework (and any associated emissions trading mechanism) as an acceptable means by which participants can meet their emission obligations. The regulators of a framework may dictate the circumstances for the use of offsetting including limits on use, and may also define criteria for acceptable offsets.

In terms of existing systems, China's experience of trading SO_2 showed that many pilot frameworks had variable rates of compliance. This was attributed to the lack of enforcement caused, in turn, by the absence of any explicit legal authorisation. Similarly, plans for the inclusion of Boston Logan Airport in a city trading framework encountered legal difficulties because the state environmental protection authorities did not have a remit to address aircraft emissions.

4.1.2 Coverage and targets

The primary purpose of LAQ emissions trading and offsetting is to establish a cost effective means of achieving compliance with regulatory obligation stemming from an overarching objective to ensure that concentrations of a given pollutant do not exceed prescribed thresholds. If emissions trading or offsetting is used to help achieve this objective, it is important that all relevant emission sources that influence the relevant LAQ pollutant concentrations are covered by the system.

As LAQ pollutants generally have impacts at or close to the point of emission, it is important that emissions are reduced within the boundary of the relevant overarching LAQ management framework where feasible. This makes trading and offsetting for LAQ management purposes fundamentally less flexible and more difficult to implement than for GHGs. However, the definition of the scope of any LAQ framework, and the conditions on the use of trading and offsets, may permit emission trades and offsets with emission sources outside the boundary of the LAQ management area to help remedy this.

It is important that any LAQ management framework recognise the need to control emissions at all locations where LAQ is a problem. When air quality improvements in one area are achieved at the expense of the air quality in another area, it could result in a “hot spot” - an unacceptably high accumulation of the pollutant in the latter area. In order to minimize hot spots, an emission trading and offsetting system that is very broad and occurs under a cap that results in emission reductions in all areas or a system that identifies acceptable compliance units by location or discounts units by location should be considered. However, if a LAQ management framework requires too many restrictions on use to avoid hotspots, it may be preferable to develop a more conventional regulatory approach to address the problem.

4.1.3 **Cost-effectiveness**

The advantage of emissions trading and offsetting is that it allows entities with high marginal abatement costs to purchase allowances and credits from entities with lower marginal abatement costs. This cost effectiveness feature is particularly relevant in relation to aviation where abatement costs are typically high. However, there is a cost point where all but the participants with the highest mitigation costs will find it cheaper to invest in mitigation measures to reduce the emissions from their own activities. It is also important for the longer term that reductions are also made within the sector to ensure it remains sustainable.

The design and management of emissions trading as part of an airport LAQ framework will also need to consider costs borne by regulated entities for monitoring, reporting and verifying emissions (or emission reductions) and for enforcement – that is, costs beyond those required to acquire allowances and credits. In the US, the RECLAIM trading framework (introduced in Section 3) required significant changes to the permit and information management systems that cost millions of dollars and additional staff resources. Generally, these additional costs should not outweigh the advantages of trading, but careful planning, preparation and management by the regulator during development and throughout the life of the programme can help to minimise this burden. In this respect the regulator must have a good understanding of the regulated entities and the factors impacting their decision-making. It is also important to note that the kinds of costs outlined above may be incurred by entities in any case, as a result of some overarching LAQ legislation, rather than a specific mechanism applied to an airport.

4.1.4 **Review Process**

The application of emissions trading and offsetting as techniques for the management of LAQ is still only developing. Indeed, many LAQ frameworks employing these techniques are in a “learning by doing” phase, and as more experience is gained, frameworks may be modified to ensure that they remain an effective means of achieving LAQ objectives. They may also have to react to external events or shocks. For example, in the US RECLAIM programme, many power generation facilities were caught without enough time to install emission controls to react to the 2000-2001 energy crisis when older more polluting generating capacity was brought back into use. This quickly drained available emission allowances from the market and required an amendment of the RECLAIM rules. The introduction, abolition or amendment of other policy instruments introduced to tackle the same impact may require changes to the LAQ framework.

The way an emitter behaves in any market will be influenced the long-term knowledge and certainty of what it will be required to do over a given time horizon. An established review mechanism could provide information that will improve the ability and predictability of changes to be made in the LAQ framework when these unforeseen external events occur.

4.2 Pitfalls to avoid

4.2.1 Over-allocation

Experience from the RECLAIM programme shows that the level of allocation influences the effectiveness of a LAQ framework. The impact of over-allocation at the beginning of RECLAIM substantially lessened the incentive for facilities to install control equipment due to the availability of inexpensive emission allowances. This problem is not uncommon in new LAQ frameworks where compromises in the level of the cap are often required to gain political agreement or to provide an adaptation period for entities to be regulated where the adaptation costs will not cause them significant financial difficulty. Some tendency to over allocate allowances in the initial years is evident from research.

This problem can generally be avoided if the allocations are based on baseline emissions that are equal or close to actual emissions. This could be achieved by averaging emissions over the preceding three to five years, for example.

Therefore, the level of allocation, at least initially, must strike a balance between the need for environmental effectiveness and the need to get buy-in to the program and allow participants to adapt at reasonable cost.

4.2.2 Free allocation

Under a LAQ framework with free distribution of allowances, existing firms get an initial allocation free while new entrants often have to purchase all allowances. Such a distribution system imposes a competitive disadvantage on new entrants. To address this concern, some auctioning of allowances could help level the playing field, or a programme of set-aside allowances could be established for facilities demonstrating that their activity levels exceeded the baseline by a certain amount.

4.3 Important factors in the effectiveness of emissions trading or offsetting systems

4.3.1 Conditions that increase effectiveness

Based on the experience and lessons set out above, it is possible to draw some general conclusions regarding the circumstances and conditions where emissions trading and offsetting are likely to be effective for LAQ management purposes. Relevant factors include:

- Where the marginal abatement cost varies widely between sources, encouraging emitters with low cost abatement options to invest in making emission reductions and selling their excess allowances to emitters whose abatement costs exceed the allowance cost.

- Where there is a sufficient number of system participants to maintain liquidity in emissions trading markets, and when offsetting is allowed where the volume of potentially eligible offset projects is sufficiently large.

- Where there is a greater uniformity of concentration of pollutants in the geographic area under consideration, rather than pockets of high concentration (so as to avoid localised hot spots)

- Where emissions trading and offsetting is determined to be the best market-based mechanism available. For example, raising the cost of emissions using an emissions tax can be relatively ineffective in a growing economy. With inflation a tax will decrease in real terms, potentially failing to meet its environmental objective unless regularly reviewed.

- Where transaction costs are relatively low.

Certain preconditions are required to ensure that any emissions trading and offsetting employed as part of a LAQ management framework is transparent, credible and has long term viability. These include:

- A sufficient level of information and scientific understanding to set a politically acceptable and environmentally-effective emissions cap for the LAQ framework

- The ability to monitor emissions to an accepted level of accuracy, track the transfer of allowances, and an acceptable capability to enforce compliance

- Permit holders who are sufficiently knowledgeable about the system and able to use the system effectively

Similarly, specific preconditions with regard to the use of offset credits for compliance within the LAQ framework also apply. These include:

- Implementing a complementary system for the generation of offset credits that represent real, additional and verifiable emission reductions;

- implementing a system that tracks offset credits to ensure they cannot be used more than once;

- establishing the rules for the use of offset credits generated outside the LAQ framework boundary that recognizes the local impact of the emissions as well as the potential for creating hot spots.

While the above factors are important in the setting of objectives for a LAQ management framework, the LAQ problem at hand, the defined objectives of the LAQ framework, and the wide ranging local circumstances including political, social and geographic influences, will determine which of these preconditions are vital for the success of the system and the relative importance of the other factors.

4.3.2 **Lessons on importance of certain factors**

Based on these lessons learned the following principles are recommended for consideration:

- Flexibility – Flexible timing, including borrowing or banking allowances, increases flexibility. (Borrowing allows a permit holder to use allowances earlier than their stipulated date, banking allows a user to store allowances for future use. Allowing borrowing or banking can make enforcement somewhat more complex.)

- Simplicity – transparent formulae make compliance simpler and reduce the incidence of challenge or manipulation. Rules should be clearly defined up front, without ambiguity.

- Monitoring and enforcement – strong monitoring or enforcement regimes have made for more effective achievement of the system objectives.

- Need for standardisation and continuous measurement.

5. AIRPORT SPECIFIC CONSIDERATIONS

In conclusion, this section summarizes the main airport-specific issues that might need to be taken into account when considering emissions trading or offsetting for addressing an airport's local air quality situation.

5.1 Emissions Trading Schemes

When considering an ETS for an airport LAQ situation, the following items should be considered.

- Has non-compliance with a LAQ regulation triggered a need for action to reduce emissions at or near an airport?

- Are there sufficient non-aircraft emission sources contributing to the problem at or near the airport to warrant incorporation in an ETS as all would have to be operated within a total emissions cap?

- Would sources operating outside the ETS cap (e.g., private vehicles) potentially undermine the benefits of the ETS?

- Is the ETS best delineated by a geographic scope, by inclusion of specific sources or by a combination of both?

- What emissions cap should be enforced to ensure that LAQ goals are achieved?

- How are allowances to be allocated?

- Can an airport operator be held responsible for emissions from private vehicles visiting the airport or used for staff travel?

- Could the use of offsets from off-site sources result in "hot spots" at the airport itself?

- How will emissions be measured or monitored?

5.2 Offsetting

- Relevant considerations and criteria for the use of offsetting include:
- Will the ETS accept offsetting as a means to meet scheme obligations?
- Should a limit on the use of offsetting be included?
- How will projects generating offset credits be monitored, verified and regulated?
- Are the projects achieving emissions reductions that mitigate the airport LAQ situation?
- What are the trading and governance procedures for emitters to buy and sell offsets?
- Could the availability and cost of offset credits determine, in part, the stringency of the emission reductions required by a LAQ framework?
- Can emission reduction projects directly funded by an airport such as transit infrastructure or city bus fleet renewal be counted as offsets?

GLOSSARY

The terms contained herein are intended to clarify concepts as used in this document.

Additionality
To avoid giving credits for greenhouse gas emission reductions that would have happened anyway, eligibility criteria have been developed to determine if the reductions are 'additional' – that is, are more than would have occurred in the absence of the project ('environmental additionality') or in the absence of the incentive from the CDM ('project additionality').

Allocation
The initial distribution of allowances to accountable entities for a compliance period. This allocation could for example be based on historical emissions or a performance standard and level of production and could be made 'gratis' or through an auction process.

Allowance (emission allowance)
An allowance is a tradable emission permit that can be used for compliance purposes in a cap and trade system. Each allowance allows the holder to emit a specific quantity of a pollutant (e.g., one tonne of CO2) one time.

Ambient air quality
The total effect of the range of sources of emissions affecting local air quality within a particular area. In contrast to an inventory, which quantifies the emissions of relevant sources, ambient air quality is quantified in terms of the concentrations (or levels) of pollutant species at any specific location.

Auctioning
The distribution of allowance - either the initial distribution or from a set-aside, this is achieved through an auction in which system participants bid for the right to purchase allowances. Different auction models could be used. Auctions often complement other forms of allowance allocation.

Banking
A banking provision permits allowances issued for one compliance period to be saved for use during a subsequent compliance period.

Baseline
A reference level of emissions. A baseline can be used for example to calculate the total quantity of allowances to be distributed under a cap-and-trade scheme or the quantity of credits generated under a baseline-and-credit (emission intensity) system. A baseline also sets the level of emissions that would occur without policy intervention in an offset program.

Baseline and credit (emissions intensity) system
An emissions trading system that establishes an emissions performance standard and allows regulated participants to generate tradable credits (or "emission performance credits/allowances") by reducing their emissions intensity below that standard. Regulated participants that remain with an emissions intensity above the standard would need to submit credits to the regulating authority.

Borrowing
A borrowing provision permits an accountable entity to use allowances for a future period to achieve compliance in the current period.

Buyer
A legally recognised entity (individual, corporation, not-for-profit organisation or government) that acquires allowances or other compliance units from another legally recognised entity (the seller) through a purchase, lease, trade or other means of transfer.

Cap and trade emissions trading system
A Cap and Trade system allows for the trading of emission allowances that are limited or 'capped' in quantity by a regulatory authority. Before each compliance period, the regulatory authority distributes the allowances through a free allocation, sale, and/or auction. At the end of the compliance period each accountable entity must surrender sufficient allowances to cover its actual emissions during the period. The trading of allowances promotes cost-efficient emission reductions, as entities that can reduce emissions at lower cost have the incentive to pursue these emission reductions and to then sell their surplus allowances to entities that face higher emission reduction costs.

Climate change
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Credit or offset credit
In this report the term ‘credit’ or ‘offset credit’ is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Distribution
The allocation of allowances among accountable entities in a cap and trade system.

Emissions inventory
A database that lists, by source, the amount of emissions of pollutants, such as greenhouse gases, that were discharged into the atmosphere over a given period of time.

Emissions trading
Emissions trading is a market-based tool that provides entities the flexibility to select cost-effective solutions to achieve their environmental targets. With emissions trading, entities can meet these targets either by reducing their own emissions or by securing through the market compliance units that take account of emission reductions achieved elsewhere.

Grandfathering
A method for the initial distribution of allowances to entities in an emission trading scheme that is based on historical data (e.g., gross emissions, entity/industry performance standard multiplied by production) and distributed free of charge.

Greenhouse gas
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent but very powerful greenhouse gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Greenhouse gas reduction or emissions reduction
A reduction in emissions intended to slow down the process of global warming and climate change. Greenhouse gas reductions are often measured in tonnes of carbon-dioxide-equivalent (CO_2e), which is calculated according to the GWP of a gas.

Hot Spots
Areas which have an unacceptably high accumulation of pollutant. Hot spots can result in the context of emissions trading and offsetting, when air quality improvements in one area are achieved at the expense of the air quality in another area.

Kyoto Protocol
An international agreement reached in Kyoto in 1997 that is linked to the UNFCCC and inscribes, among other things, the emission limitation and reduction commitments made by developed countries for the 2008-2012 First Commitment Period.

Local Air Quality (LAQ) Management Framework
A process to address a LAQ problem. A LAQ problem might be first recognised by the measured non-compliance of regulated pollutant concentrations limits. An airport operator (or other authority) might set up an LAQ Management Framework to identify and inventory the relevant emissions sources, calculate the resulting expected pollutant concentrations, take actions to achieve compliance and monitor and report results.

Marginal abatement cost
The financial cost of achieving an additional unit reduction in emissions.

Offset or offset credit
In this report the term ‘offset’ or ‘offset credit’ is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Offsetting
In this report offsetting is the activity of “cancelling out” or “neutralising” emissions from a sector like aviation using offset credits – compensating emission reductions created in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

Seller
A legally recognised entity (individual, corporation, not-for-profit organisation, government, etc.) that transfers allowances or credits to another legally recognised entity via a sale, lease or trade in return for a monetary or other consideration.

Surrender of allowances/credits
The submission of emission allowances/credits by an accountable entity to fulfil its obligations under an emissions trading scheme.

Tradable unit
A generic term for compliance units that can be traded either domestically or internationally, including allowances from a cap-and-trade system, credits from a baseline-and-credit scheme, and offset credits created from either domestic or regional trading regimes or through the Kyoto flexibility mechanisms (from Clean Development Mechanism and Joint Implementation projects).

Verification
Verification provides independent assurance that the emissions quantification and reporting have been accurately completed. The 'level of assurance' provided depends on the system requirements. In most systems the verifiers must be accredited by a standard setting organization.

Voluntary action or commitment
An action or commitment undertaken by an entity that reduces greenhouse gas emissions in the absence of any requirements to undertake such reductions.

Voluntary market
Markets in which emission reductions are purchased and then cancelled by entities which seek to manage their emissions for non-regulatory purposes.

International Civil Aviation Organization
Council's Committee on Aviation Environmental Protection (CAEP),
Market-Based Measures Task Force

— — — — — — — —

APPENDIX D

REPORT ON OFFSETTING EMISSIONS FROM THE AVIATION SECTOR

Contents

1. Executive Summary

1.1 The understanding of offsetting

1.1.1 In general terms an offset is a "compensating equivalent". As an activity, offsetting is the "cancelling out" or "neutralising" of emissions from a sector like aviation with emissions reductions achieved in a different activity or location that have been rigorously quantified and verified.

1.1.2 Offsetting can occur in either a regulatory or a non-regulatory context. In a non-regulatory context offsetting is an idealistically or politically motivated action. In a regulatory context offsetting is an action by companies or nations to achieve compliance with a mandatory emission commitment.

1.1.3 In a regulatory context it is only when credits are acquired from outside of the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

1.2 Offsetting within aviation up to now

1.2.1 Within the aviation sector, the only offsetting that is currently taking place are non-regulated voluntarily passenger based offsetting. The airlines' role is limited to offering an opportunity for the passengers to offset emissions caused by their travel.

1.2.2 Several concerns related to offsetting activities are discussed in this report. The most important relate to difficulties airline passengers have navigating on websites, limited participation, lack of transparency about the credits being offered including the general absence of rigorous verification requirements.

1.2.3 On the positive side, buying offsets mitigates greenhouse gas emissions, airline consumers are being educated about the effects of air travel on climate change, the development of carbon markets is encouraged, and the need for improved standards and verification requirements for the generation of offset credits is becoming more accepted.

1.3 Offsetting in the future

1.3.1 Despite the rapid ongoing growth of voluntary offsetting by air passengers, the potential for this type of voluntary approach for mitigating the effects of aviations emissions on the global climate change is likely limited. Despite what appears to be widespread support, the willingness to actually purchase credits on a voluntary basis has been weak.

1.3.2 Nevertheless, steps might be taken to increase demand and quality of non-regulatory offsetting. For example, ensuring offset credits meet internationally accepted rigorous standards for quantification and verification, and improving systems for tracking credits to ensure they are used only once, should be pursued.

1.3.3 Offsetting in a regulatory context may be an important tool in the future. If there is a decision to regulate emissions from aviation that allows for emission trading and emission sources not covered by a regulated system can reduce emissions at a cost less than reducing emissions from aviation itself, an offsetting mechanism is likely to be part of the scheme.

1.3.4 The report concludes with a discussion of opportunities to use offsetting in the future. At the passenger level it is possible to draw on the current voluntary experience. However, there is also the possibility of using offsetting at a global sectoral level, either in a regulated emission trading system or through an emission charge. Offsetting can also be applied at an air carrier level rather than at the passenger level. These options offer some interesting possibilities for the future.

2. Introduction – Offsetting as a means of mitigating the effects of aviation emissions on global climate change

2.1 Introduction

2.1.1 During the 7th meeting of the Committee on Aviation Environmental Protection (CAEP) in February 2007, the “Guidance on Emission Trading for Aviation” and the “Report on Voluntary Emission Trading for Aviation” were finalized.[1] Both reports are available on the International Civil Aviation Organization (ICAO) website.[2] To further CAEP’s work on emission trading and other market-based measures, the Market-Based Measures Task Force (MBMTF) was created with a mandate of scoping out several issues related to the use of market-based measures to address air emissions from the aviation sector.

2.1.2 One of the items identified for the MBMTF was to: “Examine the potential for emission offset measures as a further means of mitigating the effects of aviation emissions on global climate change”. This document was prepared in response to that request.[3]

2.2 Context

2.2.1 The Kyoto Protocol of the United Nations Framework Convention on Climate Change (UNFCCC) requires Parties listed in Annex I of the Convention (largely developed countries) to reduce their emissions of greenhouse gases.[4] The Kyoto Protocol covers the period 2008 to 2012; its successor is currently under discussion.[5]

2.2.2 The Kyoto Protocol treats international and domestic emissions from the aviation sector differently. Domestic aviation emissions are included in national targets listed in Annex B of the Kyoto Protocol.[6] Emissions from domestic aviation include emissions from civil domestic passenger and freight traffic that departs and arrives in the same country (commercial, private, agriculture, etc.), including take-

---

[1] Guidance on Emissions Trading for Aviation (CAEP-IP/20) and the Report on Voluntary Emissions Trading for Aviation (CAEP7-IP/19) were adopted by the CAEP at its 7th meeting in February 2007. It should be noted that there was a European Union reservation to this adoption.

[2] The Guidance on Emissions Trading for Aviation (www.icao.int Doc 9885); Report on Voluntary Emissions Trading for Aviation (http://www.icao.int/icao/en/env/vets_report.pdf).

[3] Steering Group Meeting CAEP-SG/20071-WP20 and, Steering Group Meeting CAEP-SG/20082-WP23.

[4] Throughout this scoping paper, reference to developed countries implies Annex I Parties; reference to developing countries implies non-Annex I Parties.

[5] A brief description of the Kyoto Protocol and Annex I Parties is available in the Glossary.

[6] ICAO Environmental Report 2007, Montreal, Quebec, page 149 (available at www.icao.int).

offs and landings for these flight stages.[7] On the other hand, international aviation emissions are not included in the national targets, the Protocol assigns the UNFCCC Annex 1 Parties, working through ICAO, the responsibility of pursuing the limitation or reduction of greenhouse gas emissions from aviation bunker fuels (see Article 2.2 of the Protocol).[8] Emissions from international aviation include emissions from flights that depart in one country and arrive in a different country, including take-offs and landings for each flight stage.

2.2.3 Aviation emissions contribute to climate change via radiative forcing (RF).[9] Of importance are emissions of carbon dioxide (CO_2), nitrogen oxides (NO_x), aerosols and their precursors (soot and sulphate), and increased cloudiness in the form of persistent linear contrails and induced cirrus cloudiness.

2.2.4 The Intergovernmental Panel on Climate Change (IPCC) 4th Assessment Report (AR4) estimated aviation's contribution to global greenhouse gas emissions in 2005 to be 3 percent.[10] The report also estimated that aviation was responsible for approximately 2 percent of the world's carbon dioxide (CO_2) emissions.[11] Total aviation RF (excluding cirrus) in 2005 was 3.5 percent of total anthropogenic radiative forcing. Including estimates for aviation-induced cirrus RF increases the total aviation RF in 2005 to 4.9 percent of total anthropogenic radiative forcing.[12]

2.2.5 Even though the aviation sector continues to improve the relative efficiency of its operations via improved scheduling/routing, fuel efficiency and other technical advances, operational adjustments alone will not mitigate CO_2 emission increases that are expected to be in the range of approximately 3-4 percent[13] per year as traffic growth continues to grow. Though the cutting or rationing of flights would be strongly resisted by aviation operators and passengers, other measures that allow the sustainable growth of the sector and contribute to further mitigation of CO_2 emissions could be implemented. For example, reductions in CO_2 could be achieved indirectly through offsetting – that is, through the purchase and retirement of emission reduction credits generated from sources outside of the sector.

2.2.6 The global warming impacts of CO_2 emissions are the same regardless of where the emissions occur. Understanding the role of offsetting in mitigating greenhouse gas emissions is becoming increasingly important. Airlines for example are providing the opportunity for their customers to voluntarily offset part or all of the emissions associated with their taking a flight. And while this service is growing in popularity among airline customers it is also being offered by a greater number of airline companies. At the same time, an increasing number of States and industries are beginning to establish

[7] IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2: Energy. Pages 3.57-3.58 (available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf).

[8] [Kyoto Protocol, Article 2, 2] "The Parties included in Annex I shall pursue limitation or reduction of emissions of greenhouse gases not controlled by the Montreal Protocol from aviation and marine bunker fuels, working through the International Civil Aviation Organization and the International Maritime Organization, respectively."

[9] Radiative forcing components arise from: emissions of CO_2 (positive RF); emissions of NO_x (positive RF), including the sum of three components: production of tropospheric O_3 (positive RF), a longer-term reduction in ambient methane (CH_4) (negative RF), and a further longer-term decrease in O_3 (negative RF); emissions of H_2O (positive RF); formation of persistent linear contrails (positive RF); aircraft-induced cirrus cloudiness (potentially a positive RF); emission of sulphate particles (negative RF); and emission of soot particles. Source: Lee et al, Atmospheric Environment, April 2009.

[10] ICAO Environmental Report 2007, Montreal, Quebec, page 104 (available at www.icao.int).

[11] Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), 2007, WGIII Technical Summary, page 49. The Report is available at http://www.ipcc.ch/ipccreports/ar4-wg3.htm. A brief description of the 'Intergovernmental Panel on Climate Change' is available in the Glossary.

[12] Lee et al, Atmospheric Environment, April 2009.

[13] Intergovernmental Panel on Climate Change, Fourth Assessment Report (AR4), 2007, WGIII Technical Summary, page 49. The Report is available at http://www.ipcc.ch/ipccreports/ar4-wg3.htm.

emission trading systems as a means to mitigate their greenhouse gas emissions. The use of offsetting is often an element of these emission trading systems.

2.2.8 Finally, flexible mechanisms under the Kyoto Protocol include offsetting and the use of this tool is growing. Understanding the role of offsetting will help the aviation sector assess its usefulness in reducing the carbon footprint of the industry.

3. Definition of offsetting

3.1 Introduction

The purpose of this section is to provide a clear understanding of the terms offsetting and offset credits as used in this report. In order to provide such an understanding, we explain how offsetting may occur and how offset credits are created. We distinguish between the activities of offsetting and the creation of offset credits and explain how offset credits may result in offsetting by being retired or cancelled.

3.2 Offsetting as an activity and the credits used for offsetting

3.2.1 In general terms an offset is a "compensating equivalent". As an activity, offsetting is the "cancelling out" or "neutralising" of emissions from a sector like aviation with emissions reductions achieved in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

3.2.2 It is important to distinguish between the activity of 'offsetting' and the creation of an 'offset credit' used for offsetting emissions - the term 'offset' has been used to refer to both. For the purposes of this paper, 'offsetting' is used to describe the action to compensate for greenhouse gas emissions. On the other hand, the term 'offset credit' or 'credit' is used to describe the product from reducing emissions that is used in the activity of offsetting. Offset credits are quantified in units of CO_2e (one tonne of CO_2 equivalent emission reductions) and can be traded.

3.2.3 Both regulated emitters (or entities) and unregulated emitters may choose to offset their emissions. A regulated entity could use offsetting as one means to comply with an emission commitment. An unregulated entity's motive for offsetting is to comply with its voluntary goals. In both cases, the emitters need to acquire offset credits that can be used for offsetting their emissions. However, the regulated entity can only use credits that are approved by a regulatory authority, whereas the unregulated entity can choose freely among the credits available for offsetting.

3.2.4 Offsetting must also be distinguished from emission trading. If for example a regulated emitter acquires emission credits or emission allowances from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to as emission trading. These credits or allowances could be used to achieve compliance with a regulatory obligation or could be banked for future use (compliance or trading). It is only when credits are acquired from outside the emission trading scheme or linked schemes and used from compliance that the activity is referred to as offsetting.

3.2.5 Thus offsetting can take place in both regulated and unregulated contexts. Offset credits that are accepted for offsetting are created according to different rules or standards. The following sections explain in more detail how credits available for offsetting are created, the standards that could be used to ensure their quality, how offsetting could take place, and finally the effects of offsetting.

3.3 Creations of offset credits

3.3.1 Many types of activities and projects can generate emission reductions which could create credits used for offsetting. For example:

- increasing energy efficiency in energy production and consumption;
- using ‘waste’ energy in cogeneration;
- fuel switching to reduce emissions of greenhouse gases generated by the burning of fossil based fuels e.g. generating electricity from renewables such as wind, solar, small hydro, geothermal and biomass energy;
- sequestration of carbon dioxide in forests and agricultural soils;
- capture and storage of CO_2 from power plants and industry;
- capturing methane from landfills or livestock; and
- destruction of potent greenhouse gases such as halocarbons.

3.3.2 In the case of aviation for example, offsetting might include the renewal of a carrier’s fleet prior to the point at which aircraft would normally be retired. The replacement of older, less fuel-efficient aircraft with newer, more fuel-efficient aircraft would result in lower emissions by the carrier. The net emission reduction resulting from the acquisition of new aircraft and early retirement of old aircraft must be verified as occurring prior to normal fleet turnover and resulting in emission reductions that would not have occurred otherwise. These net reductions can potentially be recorded as offset credits.

3.3.3 The verification of offsets as additional to that which would have occurred otherwise is an important component of creating an offset credit. Emission reductions must be over and above business-as-usual. In the example of creating an offset credit from aircraft fleet renewal, new aircraft would need to replace aircraft that had not reached their full service life. This could be defined as the number of hours an aircraft would fly before it is scheduled for a major overhaul or for retirement.

3.3.4 Offset credits are typically measured in tonnes of CO_2 equivalents ('tCO_2e'). They can be bought and sold through international brokers, online retailers or trading platforms that operate either on a commercial or not-for-profit basis.

3.3.5 Offset providers are companies or non-profit organizations that create emission reduction credits. They do this by managing projects or programs that reduce emissions that are eligible for the generation of offset credits. These emission reductions are then quantified. Some level of third party verification to confirm the reductions have been accurately monitored, quantified and reported is usually required. The credits are then issued and can be used for compliance, sold or banked for future use or sale. A tracking system to ensure the credits are used only once is also needed.

3.4 Standards and verification of offset credits

3.4.1 Offset credits can be created under any greenhouse gas regulatory system when the regulatory authority establishes or accepts procedures for the creation of offset credits including the processes for quantification and verification of reductions as well as the requirements for issuing and tracking of the credits.

3.4.2 Emission trading systems create tradable units, which allow emitters to trade between themselves to achieve compliance with their absolute cap or emission intensity target. In capped systems these are usually referred to as "allowances" and in emission intensity systems as "credits". In some cases these units have also been adopted by unregulated emitters for their own use. That is, allowances or credits from a regulated emission trading system could be used for offsetting by emitters outside the system.

3.4.3 Under the Kyoto Protocol, the approved credits to be used for offsetting are called Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs).

3.4.4 The Kyoto Protocol allows Annex I Parties to partly meet their Kyoto targets by financing greenhouse gas emission reductions projects in developing countries.[14] Clean Development Mechanism (CDM) projects generate emission credits called Certified Emission Reductions or CERs – each CER is equal to one tonne of carbon dioxide equivalent – which may then be bought or sold. Projects that generate CERs must meet a stringent set of requirements, including an additionality assessment (i.e. reductions that generate credits must be additional to those that would have occurred otherwise), contribution to sustainable development, third-party project validation and independent verification of emission reductions. The CDM Executive Board, established under the United Nations Framework Convention on Climate Change (UNFCCC), reviews CDM projects and issues CERs when all requirements are met. These credits are generally perceived as having a relatively high level of environmental integrity. According to the World Bank, in 2007 the primary CDM market traded 551 $MtCO_2e$ of CERs valued at approximately \$7.4 billion US and the secondary market[15] traded 240 $MtCO_2e$ or \$5.5 billion US of CERs.[16]

3.4.5 Joint Implementation (JI) is also a project-based flexible mechanism under the Kyoto Protocol. Here the host country is not a developing nation but another Annex 1 country. The tradable units from JI projects are called Emission Reductions Units (ERUs). JI credits are created in developed countries under their own authority (Track 1) or under the authority of the Joint Implementation Supervisory Committee (Track 2). The credits are issued by the Kyoto Party. To avoid double counting of emission reductions achieved an equivalent number of AAUs (i.e. allowances belonging to the issuing state) must be cancelled when the ERUs are issued. These projects also undergo a rigorous verification process. The JI program started much later than the CDM program and relatively few ERUs have so far been issued. The World Bank estimated the trading of Emission Reduction Units (ERU) earned through JI to be 41 $MtCO_2e$ in 2007 with a value of \$499 million US.[17]

3.4.6 Other sources of credits could be a non-profit organization that develops sustainable energy projects in developing countries and participates in a process to create credits. These processes may or may not have rigorous requirements related to the quantification, verification and tracking of reductions achieved. Common project-types for these voluntary programs include bio energy, clean non-emitting electricity generation (e.g., wind, solar, hydro), and forest-based carbon sequestration.

---

[14] Flexible mechanisms are intended to be supplemental to a country's primary focus of reducing greenhouse gas emissions internally.

[15] A secondary market occurs when investors purchase securities or assets from other investors, rather than from issuing companies.

[16] Karan Capoor, Philippe Ambrosi, "State and Trends of the Carbon Market 2008", World Bank (May 2008) pp. 19; http://siteresources.worldbank.org/NEWS/Resources/State&Trendsformatted06May10pm.pdf

[17] Ibid pp. 19

3.4.7 Emission reduction units not issued under the Kyoto Protocol are sometimes referred to as Voluntary or Verified Emission Reductions (VERs). The quality of VERs is highly variable though some assurance of quality and integrity is often provided through various standards.

3.4.8 To better ensure the quality of offset credits, a variety of formal standards and certifications for carbon offset credits have emerged, including the Voluntary Carbon Standard, International Organization for Standardization (ISO) 14064 series and the Gold Standard. The latter expands upon the CDM requirements of the Kyoto Protocol. The Gold Standard will only recognize clean energy and energy efficiency projects that meet their additionality definition and that have sustainable development benefits (such as supporting communities). Both voluntary offset projects and CDM/JI projects could be recognized under the Gold Standard. However, contrary to requirements for many regulatory programs, there is no standard for the level of verification required for a project, and no accreditation for third party verifiers.[18]

3.4.9 Government agencies in some countries provide approval for carbon offsetting mechanisms, for instance the government of New Zealand approves VER's. The role of agencies and their impact on verification process is not yet clear. As well, the United Kingdom has developed a quality assurance system for carbon offset providers. Again, it remains to be seen how government intervention will affect how permits are issued, tracked and ultimately valued in the market.

3.5 Offsetting activities

3.5.1 The activity of offsetting is separate from the creation of offset credits. For example, offsetting can be one way to meet a regulatory requirement to reduce emissions or not exceed an emission cap. In such a context, the activity of offsetting can be highly regulated with respect to the quality or quantity of credits used. In a context where an unregulated entity voluntarily undertakes to offset its emissions, the offsetting activity is not regulated though some countries have issued guidance on the types of credits that should be considered of acceptable quality.

3.5.2 A regulated emission trading system requires participating entities to monitor or calculate their emissions. In a system where total emissions are capped and emission allowances are allocated to the emitters either without cost or via sale/auctioning – a 'cap and trade system' –each entity must periodically provide the regulatory authority with allowances or credits equal to its actual emissions. An 'emission intensity system' is a system where regulated entities have an emission intensity target and there is no pre-allocation of allowances. At the end of each compliance period the entity must submit allowances or credits to cover any excess of actual emissions over target emissions or will receive credits from the regulatory authority to the extent its actual emissions are less than its target emissions. Offset credits may sometimes be used to meet the obligations of the regulated entity depending on the rules established in the system.

3.5.3 Each trading system sets its own rules for the use of offset credits including the proportion of offset credits which can be used to meet the target. For example, a large number of industrial installations located in the EU are mandatory participants in the European Union Emission Trading Scheme (EU ETS). They have the flexibility to achieve compliance under the system by submitting offset credits. However, the EU ETS only allows the use of Certified Emission Reductions (CERs) and Emission Reduction Units (ERUs) issued under the Kyoto Protocol. On average, the EU Member States have limited the proportion of offset credits that will be accepted for compliance to 13.4 percent of the installations' emissions. Other ETSs may allow the creation of offset credits by the emitters themselves. Emission trading systems can be

[18] Third party verification is often performed by a certified auditor that has a professional designation.

mandatory such as the EU ETS or voluntary such as the Chicago Climate Exchange or the proposed Western Climate Initiative.

3.5.4 Schemes to reduce greenhouse gas emissions can also be voluntarily adopted by an organization (e.g. an airline), or a citizen to compensate for actions or activities they undertake that result in the emissions. Offsetting can be undertaken e.g. for the good of the environment or to demonstrate corporate social responsibility. British Airways launched the first airline promoted voluntary carbon offset scheme via its website in September 2005. Since then, the availability of offsetting opportunities and programs for the aviation sector has multiplied, with many airlines selling carbon offsets to their passengers in partnership with offset providers.

3.6 Retirement and cancellation of offset credits

3.6.1 Credits available for offsetting can be either retired or cancelled. Retirement is the surrender of offset credits (or allowances) to achieve compliance with a regulatory or voluntary obligation or a country's international GHG commitment. Offsetting in effect allows a regulated entity or a voluntary participant to increase emissions or avoid decreasing emissions (depending on the nature of the commitment) equivalent to the value of the offset credits submitted and retired. As a result, retiring an offset credit effectively has no net impact on total emissions. However, for regulated emitters the retirement of offset credits in the place of allowances may reduce the emitter's compliance costs.

3.6.2 On the other hand, when an offset credit (or an allowance) from a regulated emission trading system is cancelled, it is removed[19] from the system and cannot be used for achieving compliance with any regulatory obligation. Similarly unregulated entities or individuals can cancel credits. In both cases a credit removed from circulation – that is, made unavailable for offsetting, has a net effect of reducing global emissions. This is the case because the reduction in greenhouse gases that was captured in the offset credit cannot be used to offset emissions occurring elsewhere.

4. Current status of offsetting in regulatory and non-regulatory markets

4.1 Introduction

Because emission trading systems set their own rules and take a variety of approaches to offsetting, examples will help to illustrate the different ways offsetting that has been used. The following three examples explain offsetting in different schemes.

4.2 Regional Greenhouse Gas Initiative (RGGI)

4.2.1 RGGI is a cap-and-trade allowance-based system established for the electricity sector in the north-eastern United States. RGGI limits the use and the location of offsets. Depending on the price of allowances, offsets can be used to fulfill 3.3 percent to 10 percent of the compliance obligation. If the price of allowances is below $10/ton[20] then only domestic offsets can be used. Above this price threshold, international GHG reductions are also eligible if they are generated within a carbon constraining program

[19] The credit or allowance is placed in an account in the tracking system (usually referred to as a 'cancellation account') from which it cannot be transferred or used for any purpose.

[20] Adjusted up or down each year according to the consumer price index plus two percent.

that places a specific tonnage limit on GHG emissions or if they are issued by the United Nations Framework Convention on Climate Change (UNFCCC) or protocols adopted through the UNFCCC process.[21]

4.2.2 The RGGI program also limits the types of eligible offset projects. At this time, only the following five project categories are eligible for offsets:

- landfill methane capture and destruction;
- reduction in emissions of sulfur hexafluoride (SF_6);
- sequestration of carbon due to afforestation;
- reduction or avoidance of CO_2 emissions from natural gas, oil, or propane end-use combustion due to end-use energy efficiency in the building sector; and
- avoided methane emissions from agricultural manure management operations.[22]

4.3 European Union Emission Trading Scheme (EU ETS)

4.3.1 The EU ETS is a regulatory trading system established by EU Member States. Apart from the trading of emission allowances, this system allows for the use of offset credits from Joint Implementation (JI) and the Clean Development Mechanism (CDM). Each Member State has to decide how many JI and CDM credits it will collectively allow its companies to use for compliance during the second phase of the system, which covers the first compliance period of the Kyoto Protocol. On average, Member States have decided to limit participant's use of credits from CDM and JI to 13.4 percent of the total cap in each Member State during the 2008-2012 period. In its Directive for the emission trading system in the 2013-2020 period, the EU Commission has introduced more extensive quantitative limitations on the use of credits from CDM and JI.[23]

4.3.2 Biomass sequestration and nuclear power projects are not allowed as potential projects, and the use of hydro-electric power is restricted to schemes meeting World Bank guidelines for environmentally sensitive implementation.

4.4 New South Wales GHG Abatement Scheme (NSW GGAS)

4.4.1 NSW GGAS is a regulatory program that aims to reduce GHG until 2012 in Australia's power sector using a mandatory GHG benchmark. This program issues offset credits for reductions achieved from specified emissions reduction projects and allows power sector participants to use these credits to meet their mandatory benchmark. This system does not allow the use of credits earned outside of the state such as those from CDM or JI initiatives.[24]

---

[21] Regional Greenhouse Gas Initiative, "Amendment to Memorandum of Understanding" (2006) http://www.rggi.org/docs/mou_amendment_8_31_06.pdf

[22] Regional Greenhouse Gas Initiative, "Overview of RGGI CO2 Budget Trading Program", (2007). http://www.rggi.org/docs/program_summary_10_07.pdf

[23] "Directive 2004/101/EC of the European Parliament and of the Council", *Official Journal of the European Union*, (November 11, 2004)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0018:0023:EN:PDF

[24] Katherine Hamilton, Milo Sjardin, Thomas Marcello, Gordon Xu, "Forging a Frontier: State of the Voluntary Carbon Markets 2008", Ecosystem Marketplace and New Carbon Finance, (May 8, 2008), pp 23
http://www.ecosystemmarketplace.com/documents/cms_documents/2008_StateofVoluntaryCarbonMarket2.pdf

4.5 Current status of offsetting in voluntary markets

4.5.1 The voluntary carbon market transacted 42 $MtCO_2e$ in 2007 valued at $265 million USD,[25] a tripling of the voluntary carbon market from 2006 to 2007.[26] This market is fragmented and for the most part operates on a bilateral over-the-counter basis rather than through a formal exchange. According to Eco Systems Marketplace research, the top two drivers for offsetting are corporate responsibility/environmental ethics and public relations/branding. While two thirds of offsetting is undertaken to compensate for organizational emissions (total or part of total emissions generated by the organization), some of the other less common purposes include offsetting emissions generated by electricity use (5 percent), commuting/vehicle use (4 percent), and business-related flights (6 percent).[27]

4.5.2 Some retailers give customers the option to pay an additional charge for offsetting the emissions associated with the product or service being purchased. Participating companies sell anything from carpeting to clothing to flights. For example, California's Pacific Gas and Electric Co. provides an opportunity for customers to offset their electricity emissions on their monthly statement. Airlines are also becoming more involved in offsetting. As of December 2007, there were 21 airlines partnered with an organization to allow for the offsetting of customers' emissions.

4.5.3 Offset providers also offer services for individuals to offset the carbon emissions from their daily activities. Individuals answer an on-line questionnaire that provides details about their lifestyle and the provider then calculates the individual's GHG emissions. Offset credits can then be purchased from the provider to fully or partially cancel out these emissions.

4.5.4 Several countries[28] offset emissions from government air travel. And many companies are becoming 'carbon neutral' by reducing their GHG emissions as much as feasible and then offsetting the remainder of the emissions. HSBC, Goldman Sachs and Swiss Re are financial institutions that have become carbon neutral.[29] Some airports, such as Christchurch International Airport in New Zealand, have also used this approach to become carbon neutral for those activities for which they have operational control, and in 2006 the Swedish airport and air navigation service provider LFV Group chose to make their whole organization climate neutral. Events by the Rolling Stones, World Cup Soccer, Super Bowl, schools, cities and even organizations like The World Bank are becoming carbon neutral.[30]

4.5.5 The Chicago Climate Exchange (CCX) is a voluntary but legally binding cap-and-trade program that uses both allowance and offset credits. In 2007, the CCX transacted 23 $MtCO_2e$ which more than doubled 2006 volumes. This 2007 volume represents a value of approximately $72 million US.[31] Offset credits can be used to meet up to 50 percent of a participant's annual emission reduction commitment.[32]

---

[25] Trading volume from the Chicago Climate Exchange excluded from this total.
[26] Karan Capoor, Philippe Ambrosi, "State and Trends of the Carbon Market 2008", World Bank, (May 2008) pp. 19 http://siteresources.worldbank.org/NEWS/Resources/State&Trendsformatted06May10pm.pdf
[27] Hamilton, Katherine *et al*: "Forging a Frontier: State of the Voluntary Carbon Markets 2008" pp 67-69 http://www.ecosystemmarketplace.com/documents/cms_documents/2008_StateofVoluntaryCarbonMarket2.pdf
[28] E.g. Norway, UK, Finland and Denmark.
[29] "Companies and Climate Change", *The Economist,* (June 8, 2006) http://www.economist.com/business/displaystory.cfm?story_id=7037026
[30] "What you can do: Go Carbon Neutral", David Suzuki Foundation, http://www.davidsuzuki.org/Climate_Change/What_You_Can_Do/carbon_neutral.asp
[31] Karan Capoor, Philippe Ambrosi, "State and Trends of the Carbon Market 2008", World Bank, (May 2008) pp. 17 http://siteresources.worldbank.org/NEWS/Resources/State&Trendsformatted06May10pm.pdf
[32] Hamilton, Katherine *et al*: "Forging a Frontier: State of the Voluntary Carbon Markets 2008, p. 39. http://www.ecosystemmarketplace.com/documents/cms_documents/2008_StateofVoluntaryCarbonMarket2.pdf.

4.6 Carbon Calculator

4.6.1 In June 2008, ICAO posted on their website an impartial, peer reviewed Carbon Emission Calculator[33] that estimates the carbon dioxide emissions from air travel for use in offset programs. The Calculator allows passengers to estimate the emissions attributed to their air travel through a simple interface that requires the user to enter only their origin and destination airports, and their class of service. The method used by the calculator applies the best publicly available industry data to account for various factors such as aircraft types, route specific data, passenger load factors and cargo carried.

4.6.2 ICAO's Carbon Calculator supports the United Nations (UN) Climate Neutral Initiative which calls for all agencies and units of the UN system to determine their total carbon emissions. It makes it possible to harmonize the emissions estimates attributable to the air travel component of their operations. UN sister agencies such as the World Tourism Organization (UNWTO) will be using and promoting the Calculator. For airline-specific programs, the International Air Transport Association (IATA) has issued guidance recommending that their members use the ICAO methodology coupled with their own airline-specific data for use in their carbon offset programs to achieve a more consistent approach to estimating the CO_2 footprint of a flight while providing more precision through airline-specific data.

4.7 Aviation emission reductions as offset credits

4.7.1 It is unlikely that emission reductions in the aviation sector will be candidates for offset projects. Research conducted by the Forecasting and Economic Analysis Sub Group (FESG) at ICAO found that the lack of an alternative fuel source in combination with relatively high capital costs makes aviation emissions more expensive to mitigate than many other sectors. The high cost of reducing aviation emissions relative to other sectors is an important reason to support offsetting which is capable of achieving emission reductions at a lower cost than could otherwise be achieved.

4.7.2 A recent analysis of all CDM projects which have been registered reveals that only 0.24 percent of projects and 0.14 percent of GHG reductions come from the transportation sector and none of these are in the aviation sector.[34] A review of two organizations purchasing credits from emission reductions projects - The Climate Trust and Swiss Climate Cent - revealed that 16 percent and 8 percent respectively of their offset credits came from transportation projects; aviation projects, if any, were not identified separately.[35]

4.7.3 The 2007 ICAO Environmental Report calculated that in 2005 total emissions from all global passenger air transport (2,022 million passengers) was approximately 600 $MtCO_2$.[36] Offsetting all aviation emissions is not likely to occur solely within the context of voluntary initiatives. However, for illustrative purposes, it appears these emissions could be offset at an average cost of less than US$6 per passenger assuming a cost of US$20 per tonne of emissions.

33 The ICAO Carbon Emission Calculator can be accessed through the ICAO website: www.icao.int.

34 International aviation is not eligible for the generation of offset credits under the CDM, though reductions from domestic aviation could be eligible.

35 Haites, Erik (2008), "Emissions Trading Systems and Transportation: An Overview of Recent Results and an Assessment of Best Practices", report prepared for Transport Canada.

36 ICAO Environmental Report 2007, Montreal, Quebec, page 189 (available at www.icao.int).

5. Status and assessment of current aviation offsetting activities

5.1 Introduction

To get a better understanding of the offsetting activities in the aviation sector an overview and assessment of relevant aviation offsetting programs are presented in this section.

A web-based review of sixteen airline offsetting schemes was conducted by the MBMTF during 2008 to inform this report. The airlines chosen for this study are mainly European, North American or Australian ranging from big companies with large global market shares to low fare airlines or smaller businesses focused on a few destinations. The companies in the study use a range of business models and offset providers to deliver this service. Some companies buy credits directly from a project partner, while others work with offset providers such as Carbon Neutral Company or myclimate. These initiatives may not be representative of all airlines' offsetting programs.[37]

5.2 Market Volumes

5.2.1 Offsetting schemes are a very recent phenomenon and the prevalence of such schemes has increased rapidly in recent years. According to Gossling et al.[38] only 6 voluntary offset providers existed in 2000, but the number grew to 40 by 2006. They noted that out of these 40 providers, 17 had started operation in 2005-2006. Few of these providers are dedicated to the creation of offset credits for use within aviation sector exclusively, but they often partner with airlines to provide the service.

5.2.2 Gossling et al. estimated that in 2005 approximately 200,000 tonnes of offset credits (CO_2 equivalent) were purchased for the purpose of offsetting GHG emissions from aviation. The authors conclude that "the voluntary carbon offsetting market is thus, in volume terms, in an early development phase, with a growth factor of 400 needed to become significant – i.e. achieving a 10 percent reduction of GHG emissions from aviation."

5.2.3 Data on the volume of offset credits purchased to offset air travel are very limited. Two major airlines in Australia have reported that in 2008, 10-12 percent of their passengers had taken up the voluntary offset option. A recent survey by Ecosystem Marketplace indicates that 6 percent of emitting activities their customers had chosen to offset in 2007 were business-related flights.[39] The Ecosystem research corresponds to a volume of 2.5 $MtCO_2e$. Compare this to Gossling et al. who estimated total carbon offsets in 2005 from all aviation-focussed voluntary carbon offsetting schemes to be a maximum of 0.2 $MtCO_2e$.[40] The escalation between 2005 and 2008 in the number of airlines offering offsetting to their customers, may explain the increase in the total annual volume of emission offset.

5.2.4 The public's increased willingness to reduce and even neutralize its own carbon footprint has helped the offset market to expand. The rising demand for offset credits is fuelled by both individuals and

[37] Note that the survey results have not been updated since its completion in August 2008, and therefore do not capture any subsequent developments.
[38] S. Gossling, J. Broderick, P. Upham, J-P Ceron, G. Dubois, P. Peeters and W. Strasdas. "Voluntary Carbon Offsetting Schemes for Aviation: Efficiency, Credibility and Sustainable Tourism". Journal of Sustainable Tourism: Vol. 15, No. 3, 2007.
[39] Hamilton, Katherine *et al*: "Forging a Frontier: State of the Voluntary Carbon Markets 2008", pp. 68-69.
[40] Note that the Gossling survey may not include an exhaustive list of schemes in place.
Gossling et al. (2007) "Voluntary Carbon Offsetting Schemes for Aviation: Efficiency, Credibility, and Sustainable Tourism", Journal of Sustainable Tourism*, 15 (3), pg. 239*

businesses and has helped the global carbon market grow by a factor of over 1.5 from 2006 to 2007. That is, in 2006 the global market transacted an estimate value of $40 billion US growing to $66 billion US in 2007.[41] A larger carbon market creates more price stability and has led to many initiatives to streamline the creation of carbon credits and to better ensure the credits represent real verified reductions.

5.2 5 Another positive effect of the growing number of individuals and corporations buying offset credits on a voluntary basis is the signal of a growing willingness to pay and take responsibility for GHG emissions. This sends a message to governments about their citizens' concerns and support for action.

5.2.6 While survey results suggest a growing interest in offsets among air travelers, or the public at large being willing to take responsibility for the emissions they cause, in reality only a small percentage of airline customers purchase offset credits when purchasing tickets. This paradox is clear from the results of a Swedish survey from May 2009 in which participants were asked whether they would consider paying an extra 50 SEK (approximately $8 US) for a flight within Europe to offset the carbon dioxide emissions of their flight.[42] The survey showed that 86 percent of respondents were willing to pay the extra cost to offset their emissions. Furthermore, 88 percent answered they thought the cost to offset the emissions should be included in the ticket price while only 9 percent answered that it should be up to the passengers to decide whether they wanted to participate in offsetting or not. In the same survey, 8 percent of respondents said that they actually had paid to offset the carbon dioxide emissions from a flight. This may be explained in part by the significant cost of offsetting for greater distances. Also, customers may not believe that their individual actions matter relative to the total action needed. It should be noted that not all of the respondents had travelled by airplane themselves.

5.2.7 In the SAS and Lufthansa study carried out in 2007 by Gossling et al., 2 percent of all respondents stated they had actually offset their emissions. Out of the 24 percent that knew about carbon offsetting, only about 8 percent of those actually compensated for the emission associated with their flights, even though the number within this group was higher than the overall result. Among respondents with a previous understanding about offsetting, 51 percent were willing to compensate future flights, while this share was 76 percent in the group who previously did not know about the concept of offsetting. These figures seem to reflect a more negative attitude towards voluntary carbon offsetting among informed travellers, who tend to show more scepticism towards offsetting.

5.3 Offset project types and sources of offsets

5.3.1 The most common offset project types supported by the airline offsetting programs include bio energy, clean non-emitting electricity generation (e.g., wind, solar, hydro), and forest-based carbon sequestration.

5.3.2 Four of the nineteen offset providers working with aviation companies in this study use only CERs while another four companies use a mix of CERs and VERs. The remaining eleven appear to use a range of VERs though the verification procedures are not always clear, and there is no accepted definition of a VER.

[41] Source: "Forging a Frontier: State of the Voluntary Carbon Markets 2008" Ecosystem Market Place and New Carbon Finance pg. 6. Available at http://www.newcarbonfinance.com/

[42] "Aviation and the Environment". (May 8, 2009). SIFO Research International.

5.4 Use of recognized standards and verification

5.4.1 The use of recognized standards for quantification and verification provides greater quality assurance of an offset credit. Greater uniformity in the quality of offset credits will allow customers to make an easier and more informed choice when shopping around for offset credits. The web-based survey of airline offsetting programs indicates nearly three quarters of the programs (68 percent) follow a recognized standard such as ISO, CDM or Gold Standard and 63 percent use either third party or independent verification. An increased uniformity in verification requirements could streamline the next generation of offset credits and increase the credibility of voluntary offsetting. Furthermore, using schemes that comply with relevant standards may also help to solve the problem of transparency by reducing the amount of information required to make an informed choice (cf. section 5.9).

5.5 The use and management of sequestration projects

5.5.1 Five of the studied airline offsetting programs work with forestry sequestration project providers. Though some of these companies acknowledge the concerns around permanency, none have identified means to address strategies related to the permanency of GHG removals from sequestration projects.

5.5.2 It is important to understand that forestry and agricultural carbon sequestration projects store carbon in the trees and soil, but this storage is not guaranteed to be permanent. Reversal events such as forest fires can cause previously stored carbon to be re-released into the atmosphere. Many offsetting programs have inadequate provisions in place to manage carbon reversals. There is limited tracking of forestry projects to ensure the carbon is preserved in the sink, and when carbon is released few programs ensure an equivalent GHG reduction/removal occurs elsewhere. Since the residence time for carbon in the atmosphere is considered to be about 100 years, forestry projects must be guaranteed a lifespan in the same order to be equivalent to the amount of carbon emissions that are being or must be offset. Where a sequestration project is offered, it is important to consider how the forest is managed and the means in place to address risks of losing the sink. Criteria may include a review of how the forest management contributes to sustainable development and whether the project provides a genuine "additional" benefit – that is, the projects would have taken place regardless of the financial incentive provided by the offset credit.

5.5.3 Unlike the Kyoto Protocol CDM initiative, some offset providers do not accept sequestration or other forestry related offset projects. The Carbon Neutral Company, on the other hand, works with forestry projects and has a 'Science and Policy Background to Sequestration by Forestry' document available at their website.[43]

5.6 Credit tracking systems

5.6.1 Most of the airline companies do not have information about how the used carbon credits are tracked or registered. Without registration and tracking the credits (or the reductions/removals from which they were created) may be sold more than once. In most cases this information is only available at the website of the offset provider. All CERs are tracked through National Registries under the Kyoto Protocol, and Gold Standard VERs are tracked using the Gold Standard Registry. Beyond these two cases, it is not always easy, or even possible, to find information about how credits are tracked.

[43] The Carbon Neutral Company, "Science and Policy Background to Sequestration Policy" Version 1.1, September 2005, http://www.carbonneutral.com/uploadedfiles/Sequestration%20by%20forestry-TCNC.PDF

5.6.2 As more air carriers develop offsetting systems, the use of credits for offsetting becomes more common. Increase in use of the airline offset systems may increase the scrutiny of credit tracking both by the general public and by the airlines themselves. An increase in transparency and accountability could help strengthen offset credit tracking.

5.7 Carbon prices and administration costs

5.7.1 Most airlines provide a fair degree of transparency about the price of offsetting a flight. There is a huge variation between the price per tonne of CO_2 that customers can pay to offset their aviation emissions. In the 2008 MBMTF study Delta was the 'cheapest' with an approximate price of 3.70 Euro (app. US$ 5) per tonne of CO_2 for a domestic flight. Lufthansa and Swiss were at the other end of the scale with a price of approximately 19.5 Euro (app. US$ 26) per tonne of CO_2. In addition, Lufthansa and Swiss add 3 Euro on amounts lower than 20 Euro to cover administration costs associated with the offsetting program. This gives a factor of almost 6:1 between the highest and lowest price per tonne of offsetting flight emissions provided by the airlines. Without explaining to the customers why airlines choose to charge the amount they do, it could be very confusing for customers and lead to mistrust towards the whole system.

5.7.2 Seven of the nineteen airline offset programs studied provide information about the share of the purchase price goes directly to offset projects. Both KLM and Virgin Blue claim that 100 percent of the amount paid by their customers goes directly to the development of their clean-energy offset projects. Among other offset providers, who provide information about the breakdown of price paid for offsetting, typically 80-90 percent of the cost goes to the project, with the remaining 10-20 percent covering administrative costs.

5.8 Coverage of non CO_2 climate impacts

5.8.1 The airlines do not typically include possible effects of greenhouse gas emissions other than CO_2 to calculate the volume of offsets needed for a flight. However, Virgin Atlantic does provide this option. When a customer orders offset credits, they have an option of paying more to "take into account other climate relevant emissions (not just CO_2)". Carbon Neutral Company sometimes offers their clients a choice - one offer claims to 'save the CO_2 *equivalent* to the flight' and offers one price of the offset, and another offer claims to 'save the same amount of CO_2 as your flight produces'. The difference in price between the two offerings seems to be the result of a multiplier of approximately 1.9.

5.8.2 It is more common among offset provider organizations that also work with offsetting aviation emissions, such as myclimate, Atmosfair, Carbon Neutral Company and Offsetters Climate Neutral Society, to use a multiplier on the CO_2 emissions to reflect what they argue is the total impact from aviation on the climate. On average they use a multiplier of 2 or 3 times the CO_2 emissions.

5.8.3 Most of the airlines clearly state that their offset schemes only account for carbon emissions. Some airlines describe the additional climate impact that aviation has due to its emissions at high altitude, but say that since the research in this area is still very uncertain they await better scientific results before including emissions other than CO_2.

5.8.4 It is widely recognized that the climate impact from aviation does not derive from CO_2 emissions alone. There are also impacts from nitrous oxide emissions (NO_X), water vapour, creation of contrails and high cirrus clouds. However, there are significant uncertainties in the estimates of the magnitudes of these effects.

5.8.5 In response to ICAO's request, the IPCC in 1999 developed a Special Report on *Aviation and The Global Atmosphere*.[44] This report estimated the Radiated Forcing Index (RFI) from aviation emissions in 1992 to be 2.7 with aviation's total contribution to radiative forcing being approximately 3.5 percent. Based on more recent scientific knowledge, data in the 2007 IPCC Fourth Assessment Report shows an RFI of 1.9 for aviation emissions in 2005, and aviation's total contribution being estimated at 3.0 percent. It is important to note that the RFI metric was never intended to be a multiplier applied to CO_2 emissions in order to account for the effects of non-CO_2 gasses. RFI is a backward-looking metric and does not permit the evaluation of a future scenario.

5.8.6 There are other metrics, such as the Global Warming Potential (GWP) and Global Temperature Potential (GTP), that strive to overcome this limitation. However, in order to properly apply these metrics, the time horizon for the analysis needs to be determined and this depends on the question that the analysis is intending to answer.

5.8.7 A weight factor has been suggested to account for the non-CO_2 effects of aviation. Based on today's knowledge, using a climate indicator similar to the global warming potential (GWP) approach and the time horizon of (100 years) used in the Kyoto Protocol, the scaling factor has been estimated to be 1.2.[45] Based on this work, another group of scientists have estimated the factor to be 1.8 if the possible effects of cirrus clouds also are included.[46]

5.8.8 Many approaches are available for addressing the impact of aviation on climate change. The answer will depend heavily on the time perspective chosen and the indicators of the effect on the climate. By using a different approach with different approaches with different climate indicators and time horizons, the estimates may change dramatically.[47] In recognition of the significant legal and budgetary considerations of choosing a methodology where scientific consensus has not yet been reached, the ICAO's calculator only computes CO_2 at this time.

5.8.9 The climate impact of aviation is also discussed by Robert Sausen and Ulrich Schumann in the ICAO Environmental Report 2007. They conclude that "...proper methods to account for the climate effects of non-CO_2 effects have still to be established, and further research must be undertaken to reduce uncertainties."[48]

5.9 Degree of Transparency

5.9.1 To provide a cursory indication of the information provided to airline customers related to the offset initiative, a simple transparency metric was used in the MBMTF study that assigns a transparency score based on the percentage of questions our researchers were able to answer in our web survey. The following questions were scored: offset provider, type(s) of offset projects, source of offsets, use of a

[44] IPCC edt. by Penner et. al.,1999, Aviation and the Global Atmosphere, A Special Report of IPCC Working Groups I and III. Cambridge University Press.

[45] Forster, P. M. D., et al. (2006), It is premature to include non-CO2 effects of aviation in emission trading systems, Atmospheric Environment, 40, 1117-1121.

Forster, P. M. D., et al. (2007), It is premature to include non-CO2 effects of aviation in emission trading systems (vol 40, pg 1117, 2006), Atmospheric Environment, 41, 3941-3941.

[46] Avinor et.al: Aviation in Norway. Sustainability and Social Benefit. Oslo 2008 http://www.avinor.no/tridionimages/Aviation%20in%20Norway.%20Sustainability%20and%20social%20benefit_tcm181-51014.pdf

[47] Piers Forster & Helen Rogers: Metrics for comparison of climate impacts from well mixed greenhouse gases and 4 inhomogeneous forcing such as those from UT/LS ozone, contrails and contrail cirrus. http://www.faa.gov/about/office_org/headquarters_offices/aep/aviation_climate/media/ACCRI_SSWP_VII_Forster.pdf

[48] ICAO Environmental Report 2007, Montreal, Quebec, pp. 182-184 (available at www.icao.int).

recognized standard, use of multiplier, verification approach, additionality criteria, sustainability, management of sequestration projects, uniqueness, information about carbon calculators, cost per tonne, percentage of fee that pays for the project vs. administrative cost, tonnes offset and money collected. A score of one was assigned for each subject area where information was provided, and a score of zero was assigned for each subject area where no information was provided.

5.9.2 According to the results of the web-based survey, the scores ranged from 20 percent to 85 percent, reflecting a wide variation in details provided on the offsetting schemes.

5.9.3 In all cases however the information is quite limited, and it is difficult for a customer to make an informed decision about the rigour and environmental integrity of the offsetting program unless they are aware of recognized standards. Many offset providers lack transparency in terms of the source of offsets, the standards applied to create offsets, the procedures followed by the offset supplier, and the emission calculator. As such, the customers in many cases have no certainty that their offsetting activity will fully compensate for the emissions generated by the air travel.

6. Opportunities for offsetting in regulatory and non-regulatory contexts.

6.1 Introduction

So far the only experience of offsetting in relation to aviation is in a non-regulatory context where the opportunity to voluntarily offset the emissions associated with their flight is offered to passengers. The fast growing development of passenger based offsetting in recent years provides an indication of the potential value for this kind of measure as a means of mitigating the effects of aviation emissions in the future. However, the opportunities for offsetting in the aviation sector could include any of the following:

1. passenger based offsetting;
2. airline based offsetting;
3. offsetting in the context of a regulatory emission trading system; and
4. offsetting through an emission charge.

6.2 Passenger based offsetting

6.2.1 On the positive side, it is clear that passenger based offsetting reduces emissions if the offset covers full CO_2 costs of a flight and the offset credits represent real and verified reductions. Furthermore, offsetting can educate consumers about the environmental consequences of aviation and possible means to reduce emissions caused by aviation. In addition, non-regulatory passenger based offsetting can stimulate the development of a carbon market. An efficient global carbon market that generates a global price for carbon is of key importance to reducing emissions of CO_2 in a cost efficient manner.

6.2.2 On the other hand, despite fast growing offsetting activities in recent years, the actual willingness to purchase offset credits on a voluntary bases has been rather limited and the demand varies significantly from passenger to passenger and from region to region. To address low participation an “opt-out” approach could be employed. Passengers purchasing tickets would be required to not to take-up, or deselect, the offset purchase during a transaction. In addition, weaknesses with current offsetting activities could also be addressed including navigation problems on websites, lack of transparency about the source of credits, uncertainty regarding the permanency of GHG removals, and the lack of adequate verification in the generation of offset credits. If these shortcomings are adequately addressed, support of voluntary passenger offsetting is likely to increase.

6.3 Airline based offsetting

6.3.1 In this report the discussion regarding offsetting in a non-regulatory context has focused on passengers. However, a more comprehensive coverage of emissions could be achieved if the initiative or responsibility to voluntarily offset emissions is transferred from the passenger to the airline. That is, aviation operators could choose to purchase offsets by incorporating the cost of offsetting into the ticket price, placing a surcharge on tickets or from other sources of revenue.

6.3.2 It will be up to the management of the airline to decide to what degree the emissions should be offset rather than the passengers. Voluntary airline based offsetting may also lead to development of voluntary emission trading schemes.

6.3.3 The most important argument against this approach to mitigating climate effects, is its voluntary nature. Airlines may choose not to offset their emissions in order to save money and increase market share on the assumption that consumers will choose lower prices over environmental responsibility.

6.4 Offsetting in the context of a regulatory emission trading system

6.4.1 Another option for managing emissions from the aviation sector would be by means of a regulated cap on emissions that allows for emission trading including the use of offset credits. Such a system is about to be implemented in the European Union where emissions from aviation will be included in the EU-ETS beginning in 2012.

6.4.2 As long as there is not a global emission cap covering all nations and sectors, which more or less always will be the case, there will be an offsetting potential within the emission trading system. Offsetting will be one of several options to comply with the obligations that may apply to the aviation sector. It is expected that access to offsetting would be of great benefit for the aviation sector faced with high reduction costs and may benefit society as a whole in providing cost efficient emission reductions.

6.4.3 Existing criticisms of offsetting could be a barrier to extensive application of offsetting in a regulatory context. Concerns about the creation of credible offset credits (for example, demonstrating the reductions would not have occurred without the incentive provided by the credit), political views of the importance of "domestic" emission reductions in preference to credit-based reductions, are examples of such criticisms. Some of these issues are touched upon in the linking report.[49] It is noted that for example in the EU-ETS aviation can only offset up to 15 percent of its emissions in the year 2012.

6.4.4 If aviation were to be included in a regulatory system, questions might arise as to the role of non-regulatory passenger based offsetting. One view is that offsetting by passengers should lead to relief of the airline's obligation. If 15 percent of an airline's emissions are being offset voluntarily by passengers, the emission cap or obligation should be reduced by an equivalent number to avoid having two sets of reductions for the same emissions. However, if voluntary offsetting by passengers were to be deducted from an airline's obligations in a regulated context, it would in effect represent a transfer of wealth from the passenger to the airline without any added effect on reducing emissions. Furthermore, there would

[49] "Scoping Study of Issues Related to Linking Open emission Trading Systems Involving International Aviation", CAEP/8 Market Based Measures Task Force. 2010

have to be some sort of control to ensure that the voluntary offsetting from passengers actually took place and that the offset credits used indeed represented real reductions.

6.4.5 An opposite view is that any voluntary offsetting from passengers should be additional to the airline's obligations in a regulated context, even if this theoretically were to result in the emissions from a specific flight becoming neutral or even negative. The argument is that passengers who decide to offset their emissions presumably do so with the intent to achieve incremental real emission reductions.

6.5 Offsetting funded by an emission charge

6.5.1 As offsetting in a non-regulated context has uncertain environmental outcomes and regulatory emission trading systems can be administratively complex, a hybrid approach can be considered which could achieve specific environmental outcomes. The approach would involve imposing a charge on fuel uplifted by international flights departing a State/region and using the revenue generated to fund the purchase of offset credits that meet agreed criteria.

6.5.2 The first steps would be to project absolute emissions from international aviation in the particular State/region and determine a net emission reduction goal (from the absolute level) and a timeframe for achieving this goal. It would then be possible to assess the cost of offset credits necessary to achieve the required emission reduction. A charge on fuel uplifted would be calculated on the basis of funding the necessary offset over a specific timeframe. For maximum efficiency the level of the charge and the identification of offset credits would be determined on a global basis though this is not essential. Verification to confirm that the revenue had been spent on obtaining the appropriate number of internationally accepted offset credits would be required.

6.5.3 Advantages of this approach include practical, transparent and relatively straight forward administration; avoidance of commercial distortions between competing air carriers while rewarding efficiency; potential for global application; and the purchase of offset credits could be targeted to developing countries thereby assisting in effort sharing among countries.

Seed Documents

Avinor *et al*., 2008. "Aviation in Norway: Sustainability and Social Benefit", Oslo. http://www.avinor.no/tridionimages/Aviation percent20in percent20Norway. percent20Sustainability percent20and percent20social percent20benefit_tcm181-51014.pdf

Capoor, K and Philippe Ambrosi, 2008. "State and Trends of the Carbon Market 2008", World Bank. http://siteresources.worldbank.org/NEWS/Resources/State&Trendsformatted06May10pm.pdf

The CarbonNeutral Company: "Science and Policy Background to Sequestration Policy" Version 1.1, September, 2005. http://www.carbonneutral.com/uploadedfiles/Sequestration percent20by percent20forestry-TCNC.PDF

Forster, P. M. D., *et al*., 2006. "It is premature to include non-CO2 effects of aviation in emission trading systems", *Atmospheric Environment*, Vol. 40, Issue 6.

Forster, P. M. D., *et al*., 2007. "Corrigendum to: 'It is premature to include non-CO2 effects of aviation in emission trading systems'", *Atmospheric Environment*, Vol. 41, Issue 18.

Forster, Piers and Helen Rogers. "Metrics for comparison of climate impacts from well mixed greenhouse gases and 4 inhomogeneous forcing such as those from UT/LS ozone, contrails and contrail cirrus". http://www.faa.gov/about/office_org/headquarters_offices/aep/aviation_climate/media/ACCRI_SSWP_VII_Forster.pdf

David Suzuki Foundation: "What you can do: Go Carbon Neutral", http://www.davidsuzuki.org/Climate_Change/What_You_Can_Do/carbon_neutral.asp

Gossling, S., J. Broderick, P.Upham, J-P Ceron, G. Dubois, P.Peeters and W. Strasdas, 2007. "Voluntary Carbon Offsetting Schemes for Aviation: Efficiency, Credibility and Sustainable Tourism". Journal of Sustainable Tourism: Vol. 15, No. 3.

Haites, Erik, 2008. "Emissions Trading Systems and Transportation: An Overview of Recent Results and an Assessment of Best Practices", report prepared for Transport Canada, March 31, 2008.

Hamilton, Katherine, Milo Sjardin, Thomas Marcello and Gordon Xu, 2008. "Forging a Frontier: State of the Voluntary Carbon".

ICAO, CAEP 2007: "The Guidance on Emissions Trading for Aviation" (www.icao.int Doc 9885) (CAEP7-IP/20).

ICAO, CAEP 2007: "Report on Voluntary Emissions Trading for Aviation" (http://www.icao.int/icao/en/env/vets_report.pdf) (CAEP7-IP/19).

ICAO Environmental Report 2007, Montreal, Quebec (available at www.icao.int).

Intergovernmental Panel on Climate Change: 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 2: Energy". Pages 3.57-3.58 (available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/2_Volume2/V2_3_Ch3_Mobile_Combustion.pdf).

Intergovernmental Panel on Climate Change: edt. by Penner et. al.,1999, "Aviation and the Global Atmosphere, A Special Report of IPCC Working Groups I and III". Cambridge University Press.

Intergovernmental Panel on Climate Change: "Fourth Assessment Report" (AR4), 2007, WGIII Technical. The Report is available at *http://www.ipcc.ch/ipccreports/ar4-wg3.htm*.

United Nations, 1998. Kyoto Protocol to the United Nations Framework Convention on Climate Change. http://unfccc.int/kyoto_protocol/items/2830.php

Lee, David S., David W. Fahey, Piers M. Forster, Peter J. Newton, Ron C.N. Wit, Ling L. Lim, Bethan Owen, and Robert Sausen, 2009. "Aviation and global climate change in the 21st century," *Atmospheric Environment*, Volume 43, Issues 22-23.

Regional Greenhouse Gas Initiative, 2006. "Amendment to Memorandum of Understanding". http://www.rggi.org/docs/mou_amendment_8_31_06.pdf

Regional Greenhouse Gas Initiative, 2007. "Overview of RGGI CO2 Budget Trading Program". http://www.rggi.org/docs/program_summary_10_07.pdf

"Directive 2004/101/EC of the European Parliament and of the Council", Official Journal of the European Union, (November 11, 2004)
http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2004:338:0018:0023:EN:PDF

The Economist: "Companies and Climate Change", (June 8, 2006) http://www.economist.com/business/displaystory.cfm?story_id=7037026

SIFO Research International: "Aviation and the Environment". (May 8, 2009).

"Scoping Study of Issues Related to Linking Open Emission Trading Systems Involving International Aviation", CAEP/8, Information Paper 23, Market Based Measures Task Force.

GLOSSARY

The terms contained herein are intended to clarify concepts as used in this document.

Additionality
To avoid giving credits for greenhouse gas emission reductions that would have happened anyway, eligibility criteria have been developed to determine if the reductions are ‘additional’ – that is, are more than would have occurred in the absence of the project (‘environmental additionality’) or in the absence of the incentive from the CDM (‘project additionality’).

Allocation
The initial distribution of allowances to accountable entities for a compliance period. This allocation could for example be based on historical emissions or a performance standard and level of production and could be made ‘gratis’ or through an auction process.

Allowance (emission allowance)
An allowance is a tradable emission permit that can be used for compliance purposes in a cap and trade system. Each allowance allows the holder to emit a specific quantity of a pollutant (e.g., one tonne of CO2) one time.

Annex I Parties or Countries
Group of industrialised countries and economies in transition included in Annex I to the United Nations Framework Convention on Climate Change (UNFCCC) that committed individually or jointly to returning to their 1990 levels of greenhouse gas emissions by the year 2000.

Assigned Amount Units (AAUs)
Emission targets for industrialized country Parties to the Kyoto Protocol are expressed as levels of allowed emissions, or “assigned amounts” for the 2008-2012 commitment period. Such assigned amounts are denominated in tonnes of CO2 equivalent emissions (CO_2e).

Auctioning
The distribution of allowance - either the initial distribution or from a set-aside, this is achieved through an auction in which system participants bid for the right to purchase allowances. Different auction models could be used. Auctions often complement other forms of allowance allocation.

Aviation bunker fuels
The international share of fuel sold to aircraft.

Banking
A banking provision permits allowances issued for one compliance period to be saved for use during a subsequent compliance period.

Baseline and credit (emissions intensity) system
An emissions trading system that establishes an emissions performance standard and allows regulated participants to generate tradable credits (or “emission performance credits/allowances”) by reducing their emissions intensity below that standard. Regulated participants that remain with an emissions intensity above the standard would need to submit credits to the regulating authority.

Benchmarking
A reference level, such as emission per unit of output, that can be part of the formula for the free allocation of allowances under a cap and trade system or that can define the target in an emission intensity system.

Buyer
A legally recognised entity (individual, corporation, not-for-profit organisation or government) that acquires allowances or other compliance units from another legally recognised entity (the seller) through a purchase, lease, trade or other means of transfer.

Cap and trade emissions trading system
A Cap and Trade system allows for the trading of emission allowances that are limited or 'capped' in quantity by a regulatory authority. Before each compliance period, the regulatory authority distributes the allowances through a free allocation, sale, and/or auction. At the end of the compliance period each accountable entity must surrender sufficient allowances to cover its actual emissions during the period. The trading of allowances promotes cost-efficient emission reductions, as entities that can reduce emissions at lower cost have the incentive to pursue these emission reductions and to then sell their surplus allowances to entities that face higher emission reduction costs.

Carbon dioxide equivalent (CO_2e)
The unit of measurement that denotes the global warming potential (GWP) of a greenhouse gas. This metric enables the impact on the climate of different greenhouse gases to be easily compared.

Certified Emission Reductions (CERs)
A compliance unit under the Kyoto Protocol issued for emission reductions achieved from project activities in non-Annex I Parties that meet the requirements of the Clean Development Mechanism (CDM). One CER is equal to one metric tonne of CO_2 equivalent.

Cirrus cloud
A type of cloud composed of ice crystals and shaped like hair like filaments. May be partly induced by aviation.

Clean Development Mechanism (CDM)
A mechanism established by the Kyoto Protocol that enables emission reduction projects in non-Annex I Parties to earn CERs that can be sold to entities in Annex I Parties for compliance with their emissions limitation or reduction commitments under the Kyoto Protocol.

Climate change
A change of climate which is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and which is in addition to natural climate variability over comparable time periods.

Contrails
The condensation trail left behind jet aircraft. Contrails only form when hot humid air from jet exhaust mixes with ambient air of low vapour pressure temperature.

Credit or offset credit
In this report the term ‘credit’ or ‘offset credit’ is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Domestic aviation emissions
Emissions from civil domestic passenger and freight traffic (commercial, private, agriculture, etc.) that departs and arrives in the same country including take-offs and landings for these flight stages.

Emissions intensity target
An emissions target defined in terms of emissions per unit of output.

Emissions trading
Emissions trading is a market-based tool that provides entities the flexibility to select cost-effective solutions to achieve their environmental targets. With emissions trading, entities can meet these targets either by reducing their own emissions or by securing through the market compliance units that take account of emission reductions achieved elsewhere.

Flexible mechanisms
To give countries with binding obligations to limit or reduce emissions more options for meeting their targets, the Kyoto Protocol contains three market-based "flexibility mechanisms” - the Clean Development Mechanism, Joint Implementation and International Emissions Trading.

Global Warming Potential (GWP)
Global Warming Potentials (GWP) are calculated as the ratio of the radiative forcing of one kilogramme greenhouse gas emitted to the atmosphere to that from one kilogramme of CO_2 emitted over a period of time (100 years). For example, with carbon dioxide assigned a GWP of 1, methane has a GWP of 23.

Greenhouse gas
The atmospheric gases responsible for causing global warming and climate change. The major GHGs are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). Less prevalent but very powerful greenhouse gases include hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF6).

Greenhouse gas reduction or emissions reduction
A reduction in emissions intended to slow down the process of global warming and climate change. Greenhouse gas reductions are often measured in tonnes of carbon-dioxide-equivalent (CO_2e), which is calculated according to the GWP of a gas.

Intergovernmental Panel on Climate Change (IPCC)
The Intergovernmental Panel on Climate Change (IPCC) was established by the World Meteorological Organisation (WMO) and the United Nations Environmental Programme (UNEP) to assess scientific, technical and socio- economic information relevant for the understanding of climate change, its potential impacts and options for adaptation and mitigation.

Joint Implementation (JI)
JI is a flexible mechanism established by Article 6 of the Kyoto Protocol for project-based emission reduction activities in Annex B countries. Emission reductions from JI projects earn ERUs.

Kyoto Protocol
An international agreement reached in Kyoto in 1997 that is linked to the UNFCCC and inscribes, among other things, the emission limitation and reduction commitments made by developed countries for the 2008-2012 First Commitment Period.

Offset or offset credit
In this report the term 'offset' or 'offset credit' is used to denote the compensating emission reductions (product) that have been achieved and can be applied in the activity of offsetting. An offset credit could equate to a one tonne reduction of carbon dioxide (CO2) emissions or a one kilogram reduction of nitrogen oxide (NOx) emissions, for example. These credits can be tradable units.

Offsetting
In this report offsetting is the activity of "cancelling out" or "neutralising" emissions from a sector like aviation using offset credits – compensating emission reductions created in a different activity or location that have been rigorously quantified and verified. It is only when credits are acquired from outside the emission trading scheme or linked schemes and used to meet commitments/obligations under the scheme that the activity is referred to as offsetting. On the other hand, if a regulated emitter acquires compliance units (allowances or credits) from another regulated emitter within the same emission trading scheme or from a linked scheme, this is referred to simply as emissions trading.

Retirement
The permanent surrender of offset credits (or allowances) to achieve compliance with a regulatory or voluntary obligation or a country's international greenhouse gas commitment.

Seller
A legally recognised entity (individual, corporation, not-for-profit organisation, government, etc.) that transfers allowances or credits to another legally recognised entity via a sale, lease or trade in return for a monetary or other consideration.

Surrender of allowances/credits
The submission of emission allowances/credits by an accountable entity to fulfill its obligations under an emissions trading scheme.

Tradable unit
A generic term for compliance units that can be traded either domestically or internationally, including allowances from a cap-and-trade system, credits from a baseline-and-credit scheme, and offset credits created from either domestic or regional trading regimes or through the Kyoto flexibility mechanisms (from Clean Development Mechanism and Joint Implementation projects).

United Nations Framework Convention on Climate Change (UNFCCC)
The UN Convention on Climate Change has been ratified by 192 countries and it sets an overall framework for intergovernmental efforts to tackle the challenge of climate change. Under the Convention, governments share information on greenhouse gas emissions, national policies and best practices, commit to GHG limitation/reduction activities/targets, and provide financial and technical support for the adaptation and mitigation activities of other countries.

Verification
Verification provides independent assurance that the emissions quantification and reporting have been accurately completed. The 'level of assurance' provided depends on the system requirements. In most systems the verifiers must be accredited by a standard setting organization.

Voluntary action or commitment
An action or commitment undertaken by an entity that reduces greenhouse gas emissions in the absence of any requirements to undertake such reductions.

Voluntary market
Markets in which emission reductions are purchased and then cancelled by entities which seek to manage their emissions for non-regulatory purposes.

— — — — — — — —

Agenda Item 4: Review of proposals relating to aircraft noise

4.1 REPORT OF WORKING GROUP 1 (AIRCRAFT NOISE) – GENERAL OVERVIEW

4.1.1 The Co-Rapporteurs of WG1 presented the working group's report. The main aim of Working Group 1 was to keep ICAO noise certification Standards (Annex 16, Volume I) up to date and effective, while ensuring that the certification procedures were as simple and inexpensive as possible.

4.1.2 The detailed work of WG1 had been undertaken by a number of ad-hoc groups and two task groups. Work items in which all WG1 members and observers had to be involved (i.e., that cover a wide range of products or that are of broad interest) were addressed by the WG1 plenary. The two task groups, Supersonic Transport Task Group (SSTG) and the Technology Task Group (TTG), were formed to undertake work on supersonic transport and technology work items, respectively.

4.1.3 Progress on items relating to amendments to Annex 16 Volume I, the work on publication of the Environmental Technical Manual Volume I, and the work by TTG and SSTG (excluding the items related to Noise Reduction Technologies Review which were covered under Agenda Item 1) are summarized below.

4.1.4 Among other completed items, the WG1 Co-Rapporteurs highlighted updates to databases including the NoisedB Version 2.7 (public version), growth and replacement database, and the "Best Practice" (BP) database. WG1 also coordinated with SAE International for an update of SAE ARP 1846 (far-field measurements of outdoor engine test stand static operation) and supported evidence reviewed by the World Health Organization (WHO) on aircraft noise and health.

4.2 PROPOSED AMENDMENTS TO ANNEX 16 – ENVIRONMENTAL PROTECTION, VOLUME I – AIRCRAFT NOISE

4.2.1 Introduction

4.2.1.1 The Co-Rapporteurs of WG1 presented a number of proposals for the amendment of Annex 16, Volume I. As stringency was not part of CAEP/8's work programme, all proposed amendments to the Annex 16, Volume I are considered stringency neutral.

4.2.2 Applicability Language (Task N.16)

4.2.2.1 With each of the previous amendments of Annex 16, Volume I, applicability provisions were revised to accommodate new chapters and situations. As a result, in the current text of Annex 16, Volume I (Amendment 9), some of these provisions are unnecessarily complex, lack clarity, and are redundant (e.g. the references in Chapters 3 and 5 to aeroplanes for which Chapters 6 or 10 are applicable).

4.2.2.2 WG1 undertook the task of clarifying the applicability provisions of Annex 16, Volume I. The work addressed the following issues:

1. the repetitious references in many of the chapters to “another equivalent prescribed procedure”;

2. the need to differentiate between applications for the approval of new types (type certificates) and changes to type designs (“derived versions”);

3. the need to harmonize the language of the applicability provisions in the various chapters, and thereby improve clarity;

4. the need to clarify the intent of the applicability provisions in respect of the appropriate amendment level of Annex 16, Volume I and revision number of the Environmental Technical Manual to be used;

5. the need to simplify the applicability provisions for propeller driven aeroplanes; and

6. the need to clarify the exemption provisions for aircraft specifically designed and used for aerobatic, agricultural, fire-fighting or external load carrying purposes.

4.2.2.3 Concerning Item 1, it was recommended to remove references to “another equivalent (application) prescribed procedure was carried out by the certificating authority” and instead make this reference only in Chapter 1, in order to make it relevant for all subsequent chapters.

4.2.2.4 Concerning Item 2, amendments to the language were recommended to address applications for new types and derived versions, noting that in most, though not all cases the Standard to be applied to a new type is also the Standard to be applied to derived versions of that type.

4.2.2.5 Concerning Item 3, amendments to the language are intended to harmonize the provisions such that common language is used across the various chapters when referring to the same thing (e.g. applications for approval of new types or derived versions).

4.2.2.6 Concerning Item 4, the applicability of the Standard to new types was recommended to be defined as of the date of submission of the application for the type certificate to the State of design. Where there are specific provisions for derived versions, the applicability of the Standard is defined as of the date of submission of the application for the certification of the change in type design to the Contracting State that first certified the change in type design. The recommended text regarding the amendment level to be used is a logical consequence of the fact that each new edition of Annex 16, Volume I incorporates all previous amendments and, on the date it becomes applicable, supersedes all previous editions.

4.2.2.7 Concerning Item 5, the definitions of “light” and “heavy” have changed many times since the introduction of Standards for “light” propeller-driven aeroplanes (Chapters 6 and 10). To accommodate these changes the applicability provisions of the affected chapters have been amended to the point where today they are complex and difficult to interpret. One example of the complexity is that currently in Chapters 3 and 5 there are exemptions for any aeroplane for which the standards of Chapters 6 or 10 are applicable. This exemption is redundant and in the recommended changes, these exemptions are removed. It should be noted that no changes to the applicability provisions of Chapters 6 and 10 are needed. Amendments to the language in the applicability provisions of Chapters 3 and 5, and Attachment E of the Annex, were recommended.

4.2.2.8 Concerning Item 6, propeller-driven aeroplanes and helicopters specifically designed for certain uses (e.g. aerobatic, agricultural, fire-fighting and external load carrying) are specifically exempted from the application of some of the chapters of Annex 16, Volume I. The manner in which each of the chapters describes this exemption is not consistent and is therefore open to different interpretations by Contracting States. It was recommended to revise these exemption clauses and to consistently refer, where necessary, to aircraft “specifically designed and used for (e.g. fire-fighting) purposes”.

4.2.3 **References to ETM**

4.2.3.1 References to the new Environmental Technical Manual (ETM) in the Annex need to be updated and clarified.

4.2.4 **CS-23 take-off speed**

4.2.4.1 The regulations for airworthiness certification (CS-23/Part23) do not require derivation of the take-off speed in terms of V2 for small jet airplanes during airworthiness demonstration tests. However, take-off speed in terms of V2 is needed in take-off noise demonstration according to Chapters 3 and 4 of Annex 16, Volume I.

4.2.4.2 In investigating this issue, WG1 determined that the take off speeds derived under the airworthiness certification requirements for small jet airplanes may, in some cases, make no reference to V2, and in other cases, the certificating authorities may apply the “Commuter Category” takeoff speed requirements contained in the EASA and U.S. FAA airworthiness certification regulations. In the latter case, the takeoff speeds are derived in terms of the V2 applicable to the Commuter Category. WG1 determined that the noise certification take off reference speed should be based on the airworthiness certification take off speeds. Therefore, in taking into account the possibility of a small jet aeroplane airworthiness certification based upon either the V2 derived under the “Commuter Category” requirements, or where the airworthiness certification requirements make no reference to V2, it was recommended that the noise certification takeoff speed requirements contained in Annex 16, Volume I, Chapter 3, 3.6.2(d) be revised.

4.2.5 **Other Technical Issues**

4.2.5.1 Several areas of Appendix 2 of Annex 16, Volume I concerning the specifications and guidance for the measurement and analysis of aircraft noise were identified for possible improvements. Six subtasks were identified within Project N.15, and substantial progress has been made.

4.2.5.2 An ad-hoc group has developed proposals representing substantial improvements of Annex 16, Volume I, and related guidance for the Environmental Technical Manual. In all cases, none of the recommended changes are considered to have stringency implications, or alter current consensus on the intent of the existing material in Annex 16, Volume I and/or related policy of any of the member State authorities. Changes have been limited to improvements in readability and clarification of previously vague or incomplete guidance. Revisions of Annex 16, Volume I related to four of the subtasks were recommended.

4.2.5.3 The proposed revisions include:

- the calculation of EPNL (Sections 4.1 and 4.4 through 4.6 of Appendix 2 of Annex 16, Volume I);

- the adjustment of aircraft noise data to reference conditions using the simplified and integrated methods (Sections 8 and 9 have been combined into a single Section 8 in Appendix 2);

- measurement and characterization of atmospheric sound attenuation (Section 2.2.2 of Appendix 2); and

- miscellaneous technical issues and editorial errors in Annex 16, Volume I (Section 3.7.3 of Chapter 3, Section 5.7.3 of Chapter 5, Note 3 of Section 1 of Appendix 2, Sections 2.3.3, 3.10.2, 4.2, 4.3.1 and 5.4.2 of Appendix 2, Sections 4.2.1.2 and 4.3.2 of Appendix 3, and Sections 3.3, 5.2.3, and 6.3.2 of Appendix 4).

4.2.5.4 The proposed change for tilt-rotors is to bring the language in line with that already adopted in Chapters 8 and 11 of Annex 16, Volume I for helicopters to clarify that the maximum rotor rpm corresponding with the reference flight condition shall be used during the noise certification procedure.

4.2.6 **Standards for supersonic aircraft**

4.2.6.1 At the present stage Chapter 12 still contains a note that recommends the noise levels of Chapter 3 to be used as guidelines for supersonic aeroplanes, while the Standard applicable to current new subsonic aeroplanes is the more stringent Chapter 4. As recommended by the CAEP Steering Group at its last meeting in June 2009, the CAEP approved the inclusion of a revised note in a consolidated proposed text for amendment to Annex 16, Volume I.

4.2.7 **Editorial Corrections**

4.2.7.1 WG1 also suggested some minor editorial corrections to the Annex.

4.2.8 **Discussion and Conclusions**

4.2.8.1 A member congratulated the noise working group on doing an excellent job in a very professional manner. The meeting also expressed its thanks to the working group for successfully concluding its task items.

4.2.8.2 The meeting agreed to the proposed amendments to the Annex 16, Volume I as shown in Appendix A to the report on this agenda item.

4.2.9 **Recommendation**

4.2.9.1 In light of the foregoing discussions the meeting developed the following recommendation:

RSPP **Recommendation 4/1 — Amendments to Annex 16 — *Environmental Protection***, Volume I — *Aircraft Noise*

That Annex 16, Volume I be amended as indicated in Appendix A to the report on this agenda item.

4.3 DEVELOPMENT OF ETM VOLUME I

4.3.1 The first Environmental Technical Manual (ETM) was approved by CAEP/1 in 1986 and published as Doc 9501 in 1988 by ICAO. To date its scope has been limited to the use of technical and equivalent procedures for the noise certification of aircraft. Since its original publication, it has undergone nine revisions. The most recent revision, approved by CAEP/6, was formally published by ICAO as Doc 9501, 3rd Edition. In addition, the CAEP/7 approved revision is available for download from the ICAO website.

4.3.2 During CAEP/5 the technical noise work programme assigned to WG1 by CAEP was revised to include the development of a new Environmental Technical Manual, specifically to explore the possibility of developing a new environmental technical manual, determine procedures for periodic review and modification of the manual, and determine a strategy and procedures for use of the guidance material by non-CAEP member States.

4.3.3 As a result of CAEP direction, the WG1 agreed that the purpose of the new ETM should be to promote uniformity of implementation of the technical procedures of Annex 16, Volume I and to provide guidance to certificating authorities and applicants regarding the intended meaning of the current Annex and those specific procedures that are deemed acceptable in demonstrating compliance to these Standards. In addition, it was agreed that the new ETM should be a companion document to ICAO Annex 16, Volume I (5th Edition, Amendment 9) and that its scope should include all the aircraft classes to which Volume I of the Annex are applicable. The structure of the resulting document should be adaptable to future amendments of Volume I of the Annex.

4.3.4 At subsequent CAEP Steering Group meetings, before and after CAEP/7, WG1 has reported on the progress of this work item. WG1 completed its work on this item and presented the complete text of the new ETM for approval to the Salvador Steering Group meeting. The SG approved the WG1 recommendation that the new noise ETM be published as Volume I of the "Environmental Technical Manual on the Use of Procedures in the Certification of Aircraft and Aircraft Engines".

4.3.5 WG1 has worked closely with the ICAO Secretariat in the preparation of the document for formal publication.

4.3.6 In the past, revisions of the ETM have been published as "WG1 approved revisions", "SG approved revisions" and most recently as "CAEP approved revisions". Publishing revisions only approved by CAEP means that they are released according to the CAEP meeting cycle, which is typically every three years. Noting that the SG meets typically each year, and in order to ensure that significant approved revisions are made available to the noise certificating community at the earliest opportunity, CAEP was invited to request the publication of SG approved revisions on the ICAO public website as they become available.

4.3.7 The WG1 Co-Rapporteur highlighted the amount of work done and the extent of coordination through meetings, teleconferences, and emails. He expressed his appreciation for the hard work done by the ad-hoc group members to successfully complete this task.

4.3.8 Discussion and Conclusions

4.3.8.1 The meeting congratulated WG1 and its ETM ad-hoc group on accomplishing this task in a very professional manner.

4.3.8.2 The Secretary noted that, similar to the emissions ETM, the title of the document would have to be finalized in accordance with ICAO procedures.

4.3.8.3 A member highlighted the need for language versions of the new ETM to also be made available.

4.3.8.4 Several members noted that the SG approved revisions of the noise ETM should be published on the ICAO website as soon as they are approved, noting that the SG can always recommend otherwise as necessary. It was concluded that ICAO Member States and industry would benefit most if the revisions are made available online as soon they are approved by the SG. The meeting agreed that SG approved revisions of ETM Volume I should be made available online as they become available.

4.3.8.5 The meeting endorsed the proposed new noise ETM as shown in Appendix B to the report under this agenda item

4.3.9 **Recommendation**

4.3.9.1 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 4/2 — Publication of Environmental Technical Manual, Volume I

That the Environmental Technical Manual Volume I, contained in Appendix B to the report on this agenda item, be published as soon as possible and that a preliminary version be made available as soon as possible on the ICAO public website.

4.4 STATE OF THE ART AND EMERGING ISSUES

4.4.1 Review and Analysis of Certification Noise Levels

4.4.1.1 CAEP/7 requested WG1 to "Provide a report to CAEP/8 on the results of a review and analysis of certification levels for subsonic jet and heavy propeller driven aeroplanes to understand the current state-of-the-art of aeroplane noise technology". WG1 established a dedicated ad hoc group to undertake this task which was comprised of members from States and Observer Organizations.

4.4.1.2 The main topics covered in the presentation included:

- what is the state of the art in aircraft noise technology and why are the noise levels where they are based on an analysis of certification noise levels;
- is the 2 vs. 4 engine noise rule difference still valid; and
- the Role of Technology in noise improvement.

4.4.1.3 Aircraft noise database utilized for analyses was the "Best Practice" database. Best Practice database is a subset of ICAO NoisedB of certificated noise levels in which only aeroplanes that follow current best practice in employing noise reduction technologies have been retained. This database also contains estimates of noise levels for soon to be certificated aeroplanes (called as Project aeroplanes) as made available by manufacturers, for example, B787, A350, B747-8 and C Series. Technological concepts considered in selecting aeroplanes for inclusion in the Best Practice database were approved by WG1. These concepts for jet powered aeroplanes include high bypass ratio engine cycles, nacelles with liners in inlets and exhaust ducts, liners in the forward fan case, minimum flow disturbances upstream of the fan blades, large spacing between fan blades and OGV, proper selection of blade and OGV counts to minimize / eliminate dominant modes from propagation, jet noise reduction approaches and airframe noise reduction technologies such as low noise landing gear devices, reduced interference between jet and flaps. Not all of these technologies may be found on each aeroplane due to valid economic and structural reasons. WG1 periodically reviews and updates Best Practice database entries to make sure that the entries represent current best practice.

4.4.1.4 The entries in the BP database cover the full range of engine thrust settings. The entries cover the highest and lowest values of maximum takeoff mass and associated maximum landing mass. Only the latest versions of a given model that have replaced previous models in the production line are retained. For example, Boeing 737-700 replaced B737-400; CFM56-5B/P engines replaced CFM56-5A on the Airbus A320 family. Out of production aircraft are included only if their design featured the technologies considered as “current” best practices and they meet Chapter 4 and they have not been replaced by a new model from the same manufacturer.

4.4.1.5 As a first step in the analysis of entries in the BP database, noise levels of aeroplanes at the three certification points were summed up and the resulting cumulative noise levels for all aeroplanes at their highest takeoff mass (MTOM) were plotted as a function of maximum take-off mass. Four-engine, three-engine and two-engine aircraft were identified so that the trends could be analysed. The WG1 representatives noted that there are very few three-engine aircraft. They also observed that there is a large variation in the noise margin across the MTOM range.

4.4.1.6 The following table summarizes the results of the analysis related to average margins for 2, 3, and 4-engine aircraft.

TABLE 1. Average margins for 2, 3, and 4-engine aircraft

Number of engines	*Cumulative noise margins relative to Chapter 4 limits (EPNdB)*		*Count*
	Average	Std Dev	
Two engines	-7.5	5.6	205
Three engines	-3.8	1.6	12
Four engines	-7.8	5.1	32

4.4.1.7 The presenters noted that 2 and 4 engine aircraft have similar cumulative margins and standard deviation. The large value of standard deviation (~ 5) for 2 and 4 engine aircraft indicates considerable scatter in the cumulative noise levels. Also, the number of 3 engine aircraft in the Best Practice database is relatively small. Hence it was decided that in order to examine the margin values of different categories of aeroplanes, the Best Practice database would be subdivided and analyzed according to five classes each representing different market segments for airlines and manufacturers: Business Jets, Regional Jets, Short-Medium range jets with 2 engines, Long range jets with 2 engines and Long range jets with 4 engines. The rationale of classifying the aeroplanes in these 5 classes is that the aeroplane mission is a major factor in aeroplane's design and performance (the same classification was employed in the CAEP Independent Expert Review for noise). Statistical analyses of the data were then performed by analyzing individual classes to provide "aggregate" trends in each class. The results are presented in the following table.

TABLE 2. Average noise margins by class of aeroplane

Class of aeroplane [range of MTOM in BP database (tonnes)]	*Min and Max Noise Margins relative to Chapter 3 (EPNdB)*						*Cum margin to Chapter 4 (EPNdB)*
	Flyover Rel. to Chapter 3		Lateral Rel. to Chapter 3		Approach Rel. to Chapter 3		
	Min	Max	Min	Max	Min	Max	
Business jets [3.9 – 45.1]	-5.5	-18.2	-2.2	-10.8	-4.6	-12.0	-15.6
Regional jets [19.0 – 52.3]	-2.1	-13.4	-1.5	-11.6	-1.2	-6.9	-6.4
Short and medium range jets with two engines [47.4 – 171.7]	-1.2	-10.7	-1.7	-8.0	-2.7	-8.7	-4.6
Long range jets with two engines [131.0 – 351.5]	-3.0	-11.7	-0.1	-8.8	-3.5	-7.7	-7.0
Long range jets with four engines [253.5 – 569.0]	-5.2	-11.7	-2.4	-8.8	-0.9	-8.0	-7.8

4.4.1.8 It was observed that flyover margins are higher than lateral and approach margins. Also, standard deviation at flyover tends to be higher than at lateral and approach (except for approach for Long Range jets with 4 engines). On the average, Business jets have more margin to rule among the 5 classes. This is most likely due to the fact that limits are constant over the MTOM range relevant to Business jets and there is a large variation in MTOM of business jets. Also, Business jets serve markets with very different requirements resulting in aeroplanes with significantly different certification noise levels and margins.

4.4.1.9 Further analysis showed that in all 5 classes the two aircraft that exhibit minimum and maximum margin at any one certification condition are almost always different than the two aircraft with minimum and maximum margin at another certification condition. In other words, an aircraft with minimum margin at one certification condition does not have minimum margin at another certification condition. In addition, as a class, SMR-2 shows the smallest cumulative margin of 4.6 dB with reference to Chapter 4 limits (or equivalently 14.6 dB with reference to Chapter 3 limits). Long range 2 and Long Range 4 engine aeroplanes show an average cumulative margin of 7.0 and 7.8 dB, respectively. Regional jets have an average cum margin of 6.4 dB. Cumulative margins for Business jets are the largest of the 5 classes. As stated before, Business jets cover a very large range of missions and have a large variation or scatter in their margins. Lateral and Flyover margins for Long Range 4 engine aircraft are somewhat larger than those for Long Range 2 engine aircraft (2 dB at Flyover and 0.9 dB at Lateral) but LR4 have a lower margin at Approach re: LR2 aircraft.

4.4.1.10 The presenters noted that many design criteria must be addressed when designing a new aeroplane. Environmental performance of the product is one of major considerations taken into account in the design process. The aeroplane manufacturer must carefully weigh each objective against all others to establish a design that meets all regulatory and market requirements. Customer needs are defined in terms of performance benefits (i.e., improvements in capacity, range, fuel consumption, speed etc., operating costs, environmental benefits (noise and emissions), and in-service reliability. Noise reduction as a design metric must be balanced with respect to other customer needs. Both aeroplane noise certification requirements and airline/aeroplane operators requirements, define noise level design requirements. Any new aeroplane must meet all current and anticipated regulatory/certification standards, and operate at all airports where the customer anticipates service.

4.4.1.11 For the introduction of new technologies, the impact of bypass ratio on noise for a variety of aeroplanes incorporating different design features was discussed. Increase in intake and cowl length generally offer better opportunities for installation of acoustic treatments resulting in increased acoustic liner area, but also potentially introduce weight and drag penalties. These penalties become more and more significant as the bypass ratio increases.

4.4.1.12 Regarding the steeper variation of noise versus weight, large difference of margin within a given family are due to the range of weight and thrust needed to cover operational requirement in an optimum way. During the production life of a model, a number of increases in the takeoff weight and engine thrust are made available to meet the operators' needs for longer range, improved takeoff performance, and higher capacity operations. It is not uncommon for the growth versions of an aeroplane to reach weights that are in the order of 42% higher than the initial model entered into service a few years earlier.

4.4.1.13 It was also explained that larger margins for larger airplanes are seen, not because they are larger but because they include a number of airplanes into which most recent noise reduction design concepts and technologies have been incorporated. This is mainly due to economic reasons because large airplane programmes have potentially a better capability to absorb higher development costs. The choice of developing a brand new aeroplane model instead of a derivative configuration based on an existing model is often based on the outcome of a balance between performance and economic considerations. In many cases, noise reduction potential for a derivative design is less than that of a completely new design where typically better opportunities for implementation of the latest available low noise technologies and design features exist.

4.4.1.14 In conclusion, despite significant gains for LR2 and LR4 airplanes, only incremental changes for SMR airplanes have occurred in recent years because no brand new airplane programme has been launched yet in this category enabling incorporation of new technologies that have been recently developed and implemented into larger airplanes for which the market has required the development of new models. Analysis supports the current difference in the flyover noise limits of the 2-engine and 4-engine aeroplanes. Within an aeroplane family, noise increases with mass faster than indicated by the slope of Chapter 4 Standard. Across families of aeroplanes, increases in noise with mass are more in line with the slope of Chapter 4 Standard. It was also concluded that a different balance of design requirements yields different noise levels and margins, noting in particular that design of some aeroplanes have been heavily influenced by stringent noise targets in order to meet specific customer and market demands.

Discussion and Conclusions

4.4.1.15 The meeting took note of the work accomplished by WG1 in the review and analysis of subsonic jet and heavy propeller-driven aeroplanes' certification noise levels, against current certification limits, including assessing the separate Flyover noise limits for two and four-engine aeroplanes.

4.4.1.16 A member asked whether it was accurate to describe the work as a "state of the art" aircraft analysis, when out-of-production aircraft have been included in the database upon which the analysis is based. The presenter stated that, although some out-of-production aircraft are included, they do employ best design practices and are included only if they meet Chapter 4 levels.

4.4.1.17 The member also inquired as to the differences between long range aircraft, where considerable advances have been made, and the single-aisle aircraft where this is not the case. The presenter clarified that for single aisle aircraft, there have been advances in technology but since no brand new design have been introduced for almost twenty years, the full potential of incorporation of all new technologies has not been realized.

4.4.1.18 The member also requested clarification on the availability of technologies where some new designs have been influenced by customer requirements (e.g. for specific UK and US airports) resulting in significant noise improvements. It was clarified that although technologies exist to design quieter aircraft, interdependencies between different aircraft design requirements play a major role in new technologies incorporation, thus the potential gains may not be the same for all aircraft.

4.4.1.19 A member complimented the task group on their analysis. Similar to the previous line of questions, he wondered whether the margin variation between 0 and 14dB was caused by the use of different technologies. The member also noted that in all classes of aircraft there are aircraft with large margins and the question arises to whether noise reduction technologies have been applied to these but not the ones with smaller margins. The presenter clarified that the technology is not the only factor in such variation. There are other factors such as increase of weight and thrust differences as well as different design characteristics that respond to different types of market requirements. In other words, the answer is not necessarily the same for all aircraft with similar margins where some large margins are caused by low weight variants while others are caused by specific technologies. The presenter indicated that a better indicator of the latest technology implemented would be the certification date of an aircraft. It was emphasized that each aircraft design responds to specific market requirements.

4.4.1.20 A question was also asked whether there exists the opportunity to improve noise margins of larger aircraft. Also, based on improved margins for newer aircraft, which implies the current availability of technology, the question was raised on whether a Standard could serve as a driver for technology incorporation. It was clarified by the presenter that if a new aircraft is designed then it could be much quieter. The member enquired if that statement disregarded interdependencies and trade-offs. The presenters agreed that trade-offs play an important role in any design and that the manufacturers respond to market requirements which can push the design with different trade-offs. Moreover, some technologies incorporated in large aircraft are not scalable to smaller aircraft.

4.4.1.21 A member appreciated the work done by the group. She expressed general support for the analysis but would recommend that the use and content of the BP database be improved in future WG1 work.

4.4.1.22 An observer expressed concern over the use of the terminology "best-practice" equally to apply to all aircraft independent of their margins to Chapter 4. These margins in the database show a large variation. He also expressed that each aircraft is weighted equally regardless of whether it is out of production or of low production volume. A member remarked that consideration of number of aircraft is more in line with MODTF activities. The chair clarified that these are two different types of analyses.

4.4.1.23 A member asked whether a definition of "marginally compliant" aircraft was needed, similar to existing regulation in the EU. Another member noted that ICAO does not recognize such a definition and formally expressed her disagreement with the concept and consideration of such a definition by ICAO.

4.4.1.24 An observer highlighted that the state-of-the-art analysis was a WG1 task and therefore all members and observers in the WG are welcome to provide input into this analysis and particularly to the definition of BP database and its use.

4.4.1.25 The Chair again thanked the group for carrying out this detailed analysis. He noted the meeting's concerns related to the BP database and stressed the importance of continuing discussions on the subject during the consideration of future work in agenda item 5.

4.4.2 **Development of stringency scenarios**

4.4.2.1 At the Steering Group in June 2009, a future work item on a new noise Standard for subsonic jet and heavy propeller-driven aeroplanes was discussed. WG1 suggested the following more precise wording: "Review and analyze certification noise levels for subsonic jet and heavy propeller-driven aeroplanes and, based on the analysis, develop stringency scenarios for impact analysis considering open rotor technology".

4.4.2.2 For such a work item, WG1 expects its deliverable to be a proposed set of noise stringency scenarios which, upon Steering Group approval, would be evaluated by MODTF for the scenarios' corresponding environmental costs and benefits including the interdependency effects, and by FESG for the corresponding economic analyses. In order to ensure sufficient time for MODTF and FESG to conduct their analyses, the deliverable defined above would need to be completed no later than the Steering Group meeting in 2011.

4.4.2.3 One member presented its view that the WG1 interpretation does not take into account a number of important considerations and needs to be revised. It was stated that it may be premature to develop more stringent Standards beyond Chapter 4 at this time given the following considerations:

a) the timing for narrowbody (short/medium range twin-engine) aircraft new technology replacement is uncertain, as manufacturers continue to postpone their new technology replacement decisions while there has not been any significant noise improvement in this class of aircraft over the past two decades;

b) uncertainty in the airframe/engine configurations, especially with respect to open rotor engines and to a lesser extent geared turbofans, suggests that data may be unavailable for noise stringency considerations by CAEP/9 and without such data, there is considerable risk of making noise stringency decisions for new type designs that may inadequately account for environmental interdependencies;

c) a preliminary analysis suggests that modest stringency increases cut across a greater range of manufacturers, aircraft classes and families than when Chapter 4 noise limits were set; and

d) given limited resources and number of specific requests related to climate change, especially the development of an aircraft CO_2 emissions Standard, work related to international aviation and climate change will need to take precedence at this point.

4.4.2.4 The member therefore suggested that WG1 be tasked to develop a schedule showing when data for project aircraft (i.e. not yet in production but expected to enter service such as narrow-body replacement aircraft), especially with new engine technologies (open rotor and/or geared turbofan powered), will be available for stringency analyses. WG1, with assistance from MODTF and FESG, should conduct a scoping study, using existing data, of the viability of a range of stringency options using currently available data and methodologies (e.g., CAEP/5 cost assumptions and CAEP/8 noise goal analysis). At the same time, FESG could perform preparatory work for economic analyses of noise stringency scenarios during the CAEP/9 work programme. All such work by WG1, MODTF, and FESG could be presented to the second Steering Group meeting in the CAEP/9 cycle. The member suggested that WG1 should recommend a realistic schedule for establishing a new noise Standard with the above considerations in mind. She highlighted that there were ongoing discussions in CAEP on possible ways forward on the subject and that she would be happy to further consider these possibilities.

4.4.2.5 An observer, presented the position of several members from one region that new work be undertaken to support a decision to increase stringency by 3-10dB cumulative relative to Chapter 4 at the CAEP/9 meeting. More specifically, they proposed that the CAEP/9 work programme include tasks aimed at considering, by 2013, a noise stringency Standard 6 to 10 dB below the current Chapter 4 Standard applicable to **new types** from 1 January 2016.

4.4.2.6 Elaborating on their proposal, the observer presented the following arguments for the necessity of working on noise stringency in 2010-2013:

a) Between 1990 and 2002, noise exposure of populations around airports generally fell as a result of the phase-out of Chapter 2 aircraft. However, noise exposure at many airports increased after 2002 due to the continued passenger traffic growth. The trends assessment shown by MODTF under Agenda Item 1 proves that there is an increasing impact in all scenarios except low growth.

b) There is growing public debate and concern about the adverse health effects of aircraft noise. This is leading to specific noise requirements at an increasing number of airports in the members' countries resulting in growth-constraints. As observed in the state-of-art analysis report, it is clear that local rules and hence specific customer requirements and not the ICAO Standards are directing the design of aircraft. Absence of global Standards will result in a proliferation of local rules, potentially making the ICAO Standard setting process irrelevant.

c) For the largest aircraft, industry has demonstrated that the technology to meet the noise challenge is commercially available and beneficial. It is reasonable to assume that much of this technology could be applied to the full range of aircraft sizes. It was believed that assertion of "short and medium-range aeroplanes (Class 3) have not had significant noise improvements over the past two decades" is not caused by a lack of technology availability but by a lack of incentive. The current Standard was identified as a cause in plateau-ing of cumulative margin at certification for such aircraft (30-100 tonnes).

d) A new Standard is required to influence the design of re-engined variants of the current single aisle aircraft likely to be launched in the period 2016-18. Delaying consideration of a new standard to CAEP/10 would risk these variants of the current single aisle aircraft being introduced without the latest technology.

e) The level of stringency at CAEP/9 should not disincentivize development of open-rotor type engine technology, but rather would consolidate the gains already made and allow any new high volume single aisle aircraft launched in the near future to be influenced by the new Standard.

f) If the old aircraft models including out-of-production and low-production volume aircraft are excluded from the best practice database, relatively few aircraft will be impacted by a potential new Standard.

4.4.2.7 The observer proposed that CAEP WG1 be left to decide which stringency options should be analyzed in a range upto 10dB cumulative below Chapter 4 with an effective date of 1 January 2016.

4.4.2.8 In order to address concerns that work on a noise stringency analysis would not be feasible during the CAEP/9 cycle in parallel with the priority work on a CO_2 Standard, the observer provided a plan to demonstrate that it is possible to perform both tasks effectively within the three-year CAEP/9 cycle.

4.4.2.9 An observer supported the recommendation of a study for increasing noise stringency by emphasizing that updating the noise Standard is the principal and the only guaranteed instrument for addressing aircraft noise at source among the four elements of the Balanced Approach. The observer expressed concern over the criteria used for inclusion of certain out-of-production or low-production-volume aircraft in the best-practice database. It was further noted that noise stringency on the CAEP/9 agenda for 2013 could result in a new Standard not implemented 10-12 years after the introduction of Chapter 4.

4.4.2.10 A member presented his views on a new noise Standard. He gave an overview of the analysis where relatively new aircraft built in his State were included in the list of non-conforming to a Chapter 4 minus 5dB Standard. The paper also points out that further studies on interdependencies are needed before the development of a Standard for future aircraft. The design and eventual adoption of future noise stringencies by CAEP is a critical issue since it encompasses the interests of local communities, manufactures, air carriers, airports, air traffic controllers and policy makers. For this reason, the development and implementation of noise stringencies that are basically the imposition of limitation of aircraft noise (the main noise source) will not necessarily reduce the number of people affected by aircraft noise worldwide. Moreover, those stringencies, if not carefully planned and implemented, can generate adverse effects in some important stakeholders compromising the sustainability of their business. This is especially true since the industry is still recovering from the worldwide financial crisis of 2007-09 and that an early development of a new noise Standard could be especially harmful for manufacturers and operators from developing countries. The member shared the view of another member that a conservative position be taken regarding establishment of a new noise Standard at the next CAEP meeting.

4.4.2.11 An observer presented his position that the setting of a new noise certification Standard in the CAEP/9 cycle would be premature. He quoted the noise IEs that the noise performance of an airplane is the result of a complex combination of the airframe and the engine design. The technological changes associated with acoustic performance therefore are much more complex than those associated with NO_x, which involve combustor technology alone. In addition, he remarked that the state-of-the-art technology from which the improvements are derived must be implementable across the spectrum of the future fleet according to the CAEP principle of technological feasibility. He further recalled the WG1's analysis which showed that the current state-of-the-art airframe and engine combinations provide only marginal improvements to the CAEP/5, Chapter 4 noise Standard. This could be explained by the fact that the Chapter 4 Standard became effective only 4 years ago. The observer concluded that the data indicated that it is premature to consider new noise stringency, as the airframe and engine technologies that could bring significantly enhanced noise performance need to mature beyond Chapter 4 before a new generation of state of the art technologies can be implemented across the fleet. Furthermore the uncertainties related to the open rotor engines trade-offs for emissions and noise necessitate that more time be given for technologies to mature and that decisions can be made when more accurate data is available. Furthermore the trends assessment data shows no significant increase in noise impact until year 2026.

Discussion and Conclusions

4.4.2.12 The Chair noted that, as the Co-Rapporteur of MODTF, he could state that MODTF analysis showed noise contours while assuming a fixed population. Increasing population densities within or outside contour areas was not taken into account in the MODTF analysis.

4.4.2.13 A member requested clarification on the issue of open rotors. Some presenters had stated that the lack of data could preclude any consideration of a new Standard. In his opinion, Standards for future aircraft with open rotor engines could follow the model of supersonic aircraft. In this way, the Standards for current subsonic aircraft could be decided now and once open rotor technology is proven, a new and possibly separate focused Standard for this technology could be formulated in a new Chapter of the Annex 16 Volume I. A member responded that she opposed a separate, less stringent Standard for open rotor aircraft.

4.4.2.14 An observer stressed the importance of analysis that will enable CAEP/9 to decide whether a more stringent noise Standard is technically feasible, economically reasonable and environmentally beneficial and, if so, what the appropriate increase in stringency would be. He thought such an analysis during CAEP/9 was feasible while acknowledging that the development of a CO_2 certification requirement and Standard will have the highest priority in the CAEP/9 work programme.

4.4.2.15 The Secretariat requested a clarification from the observer on whether he was excluding the option of increasing stringency according to the Chapter 3 model (threshold levels for three different certification points) since he had only mentioned scenarios for cumulative noise margins. The observer clarified that no options were being excluded.

4.4.2.16 A member sought another clarification on whether a study on phase-out was being requested while noting that she would not favour any phase-out studies. The observer confirmed that no analysis for phase-out scenarios was being proposed for consideration. He added that his proposal for a study applied only to new aircraft types and not to in-production aircraft.

4.4.2.17 A member questioned whether the case for analyses of scenarios with a cap of 10dB margin to Chapter 4, and the statement of the observer regarding cost effectiveness of 6-9dB margin scenarios were justified by the data presented by WG1. The observer replied that these assertions are based on information available to him that such a Standard would not risk or impact any development of open-rotor engines. The statements were basically qualitative and were intended to bound the analysis and facilitate the task within CAEP working groups.

4.4.2.18 Another member remarked that the WG1 Co-Rapporteurs have not indicated any necessity of an increased Standard. The only studies that can be carried out are related to technologies.

4.4.2.19 Several members and observers highlighted the need for a continued review of noise Standards while acknowledging the current emphasis on aviation and climate change.

4.4.2.20 A member noted that most members may be misconstruing the noise impact of open rotors which from past experience in his State with more than 200 engines, showed that such aircraft designs struggled to meet Chapter 3 Standard and therefore, for such aircraft, it would be difficult to meet the Chapter 4 Standard. The promises of quieter open rotors that have been put forward are not based on tests. He also cautioned against arithmetically adding the noise benefits and highlighted the potential adverse outcomes of any measures.

4.4.2.21 A member stated that Standards should not be based on single aircraft results but be based on fleet-wide studies. With that being said, he supported continuation of studies within WG1 and MODTF on future Standards that could be reported at CAEP/9 without the expectation that an agreement on a new noise Standard would be reached at CAEP/9.

4.4.2.22 The Chair thanked all members and observers for their input. The meeting agreed that studies on noise stringency scenarios should continue without an agreement at CAEP/8 that a Standard will be agreed upon at CAEP/9.

4.4.2.23 A member expressed his concern with introducing too many Standards which might burden the industry. Therefore, in his opinion, consideration of a new noise Standard may be premature. The member expressed the special noise concerns in his State due to a small area with a large population.

4.4.2.24 A member agreed that although climate change is the highest priority, he was not opposed to studying noise stringency scenarios. He also noted the trade-offs between timing and levels of stringency and that in this respect a higher Standard later might be better.

4.4.2.25 A member agreed with some other members and observes that a noise Standard is premature. Furthermore, economic downturn means that airlines in developing countries are suffering. However, he had no objection to further studying the issue.

4.4.2.26 An observer highlighted the principles of environmental benefit, technological feasibility, and economic reasonableness when considering any potential Standards while taking into account interdependencies with other environmental parameters. He suggested revisiting the WG1 proposed description of the proposed work item since that was a consensus WG1 position. He further highlighted the implications of cost of development and the long timeframes over which these impacts are felt by the industry. Such considerations should be included in any consideration of policy decisions.

4.4.2.27 A member agreed with considering each certification point as well as cumulative margins. She also encouraged CAEP to think about timing and an upper limit for a stringency analysis when it comes to future work discussions.

4.4.2.28 A member highlighted the issue of trade-offs where any study on a noise Standard must account for the findings from the work on a CO_2 Standard.

4.4.2.29 A member emphasized that ICAO should take steady measures and establish policies that do not cause unnecessary harm. He expresses his concern that the database should be further developed. He recalled that industry incorporates new technology in aircraft when it is mature. If the technology is not feasible, then such incorporation may mean unprofitability of the venture and the losses accumulate with time. In his opinion, the simultaneous introduction of a noise and NO_x standard will be burdensome on industry. At the same time, fuel burn, noise and emissions trade-off should be properly taken into account. He also remarked that any new noise Standard should be equitable and not be a barrier to new entrants. He welcomed the technical analysis presented and offered additional data from his State, on open rotor issues.

4.4.2.30 Some members supported a position by some other members and observers that it would be premature to consider a noise Standard because of its potential impact on operators and their investment in the current fleet of aircraft.

4.4.2.31 A member reminded the meeting that continuous review of noise Standards is a core task of this committee. It was hoped that this analysis should continue and, while acknowledging the higher priority of a CO_2 Standard, the committee should review analysis of difference noise stringency scenarios at CAEP/9.

4.4.2.32 A member, from the group of countries having put forward a joint proposal, reemphasized that studies on the feasibility of a new noise Standard were required. CAEP is a technical committee of the ICAO Council and it should continue to look at updating Standards based on the availability of new technology. This is essential if ICAO and CAEP want to maintain leadership in aviation environmental issues. This can be done only if Standards are based on mature state-of-the-art technologies. He also clarified that the proposal was that analysis be confined to application to new aircraft types and therefore should not impact economic costs of airlines.

4.4.2.33 An FESG Co-Rapporteur commented that FESG and MODTF do not currently have the resources and the capability to undertake two analyses simultaneously. However, the plan proposed by a group of States to conduct stringency analysis for noise and CO_2 assumes the best case scenarios and does not take into account potential delays and resources issues that could impact the timelines suggested. She also highlighted the additional uncertainties where models and databases would have to be extensively updated or entirely new capabilities would have to be developed.

4.4.2.34 A member expressed his support for the position taken by a group of States from his region. He believed that CAEP should request that an analysis be performed that will enable CAEP/9 to decide whether a more stringent noise Standard is technically feasible, economically reasonable and environmentally beneficial and, if so, what the appropriate increase in stringency would be. This can be done in parallel with the development of a CO_2 certification requirement and a Standard which will have the highest priority in the CAEP/9 work programme. He also noted the synergies between CO_2 and noise Standard analysis.

4.4.2.35 A member noted that simplified timelines presented earlier by an observer did not fully reflect all the technical discussions and the recommended that the Co-Rapporteurs develop a more detailed schedule.

4.4.2.36 A member remarked that the graphical representation of the overall plan of noise and CO_2 analyses shown by a group of States may be too simplified without showing all the complexities behind it.

4.4.2.37 An observer expressed his support for the position that consideration of a noise Standard should not be constrained by the potential of aircraft with open rotor engines which in any case, may require its own Chapter in Annex 16.

4.4.2.38 Some observers supported earlier stated positions of other members and observers that consideration of a noise Standard would be premature at this stage. An observer also agreed with the FESG Co-Rapporteur that a proposed plan seemed ambitious especially for WG1. He also noted that certification data for some new aircraft types is expected to be available imminently after potential completion of milestone one.

4.4.2.39 An observer clarified that some airports that have almost all Chapter 4 aircraft still have noise issues because of close-in populations or other similar reasons.

4.4.2.40 A member clarified that the position stated by a FESG Co-Rapporteur could not be construed as a position of FESG or MODTF since this had not been discussed at a group meeting. He informed the meeting that the plan put forward represented a realistic timeframe and took into account opinions of several members of FESG and MODTF. He also remarked that the questions being asked by some members and observers are the ones that will be answered by the proposed analysis of stringency options. He further remarked that all the uncertainties being mentioned regarding a noise Standard also apply to a potential CO_2 Standard where the meeting has taken the position of going forward with a Standard.

4.4.2.41 The chair concluded by noting the position of some members and observers that it will be premature to decide a Standard at CAEP/9 and there might be associated risks to the industry. There was support for further studies that incorporate interdependencies within environmental parameters and with economic costs. He acknowledged the position of some members who stated that committee should continue one of its core tasks of assessing new Standards. This could be done by keeping the noise Standard option open for CAEP/9 and not committing to it already at CAEP/8. The chair invited members and observer to continue these discussions under the future work agenda item.

4.4.3 **Review of Supersonic Transport Issues**

4.4.3.1 The SSTG has continued to investigate the possibility of adopting subsonic noise certification Standards for supersonic aeroplanes. Annex 16, Volume I currently contains in Chapter 12 a recommendation that the Standards of Chapter 3 be used as guidelines for new supersonic aeroplanes. The more stringent standards of Chapter 4 are currently applicable to new subsonic aeroplane types. After considerable discussion, it was agreed in SSTG that there was insufficient detailed information about the configurations and associated technologies that would be used for future supersonic aeroplanes to permit definition of appropriate detailed noise certification Standards for such aeroplanes (reference also the proposed amendments to Annex 16 Volume I).

4.4.3.2 The SSTG has been taking a more active role in helping to define and direct research that is intended to define sonic boom acceptability criteria. The United States proposed in WG1 that SSTG help develop a roadmap for such research. SSTG chartered a second ad-hoc group to work towards drafting an initial roadmap for a programme to develop such acceptability criteria.

4.4.3.3 With the help of the Research Focal Points, the SSTG is continually monitoring the state of sonic boom knowledge. SSTG has come to the conclusion that the state of such knowledge is not sufficient at this time to trigger development of Standards for sonic booms. It is intended that the roadmap and resulting research will focus research on defining sonic boom acceptability criteria that would then permit the start of development of sonic boom Standards. Preliminary schedules from the roadmap project would indicate that it may be appropriate to begin developing such Standards sometime after the middle of the next decade.

4.4.3.4 The Research Focal Points (RFPs) presented a report summarizing the current understanding of sonic boom noise. It included a brief background on the overall nature of sonic booms and the problems arising there from. Significant research has taken place in the last three years. The progress in recent past as well as the general issues was reviewed with a focus on what was known and not known, particularly regarding human response to “low” sonic booms. The conclusion of the RFPs was that at this time, ICAO should not yet revise Resolution A33-7: Consolidated statement of continuing ICAO policies and practices related to environmental protection, Appendix G – Supersonic aircraft – the problem of sonic boom. More information is needed before regulations are reconsidered. It is very important that research be continued on the largest possible scale on the effects of “low-boom” sonic boom noise on humans, wildlife and structures, particularly regarding sonic boom noise heard and/or felt indoors. Research should also be continued on supersonic design and atmospheric propagation.

Discussion and Conclusions

4.4.3.5 A member inquired whether any States have allowed or are considering allowing supersonic flight over land as this was not the case in his State. Another member informed the meeting that her State has initiated a series of meetings to encourage a public debate on the issue. One member provided the information that Concorde flights over large parts of his State used to be allowed although any such permission for future supersonic aircraft is uncertain.

4.4.3.6 An observer commented that it is the responsibility of the industry to prove that supersonic flight is acceptable in environmental terms.

4.4.3.7 The Secretary informed the meeting that ANC has been periodically informed about the status of supersonic boom research and the progress in technology with a view to ensure that the need for developments in other areas such as airworthiness and operations could be timely considered.

4.4.3.8 The meeting noted the current status of discussions and observations from WG1. It agreed that in view of the uncertainties, although acknowledging the value of the draft roadmap, no firm goals or timelines could be determined at present.

4.4.3.9 It was agreed that, for the present, States should continue to be encouraged to provide any information they might have which might help to advance the debate on supersonic transport.

4.4.4 **Noise Model Scoping**

4.4.4.1 The MODTF Co-Rapporteurs described that there are three organizations that currently maintain responsibility for standardization/guidance of commercial aircraft noise modelling. These include ICAO/CAEP, the SAE International’s A-21 Committee, and the European Civil Aviation Conference’s Airport Noise Modelling Group (ECAC/AIRMOD). Currently, these organizations develop separate noise modelling guidance, which in large part is duplication of work.

4.4.4.2 It was proposed that CAEP's Modelling and Database Task Force (MODTF), with support from CAEP's WG1, take the lead in coordinating global noise modelling guidance. This process would result in updates to ICAO/CAEP Document 9911, which in principle, could then be adopted within relevant SAE A-21 and AIRMOD documentation. This work item would be handled by a task group within MODTF.

Discussion and Conclusions

4.4.4.3 A member agreed with the MODTF proposal. She highlighted that this approach was consistent with the previous approaches to build upon existing expertise as much as possible. This was the case for alternative fuel related tasks being coordinated with WG3.

4.4.4.4 Another member supported the work item and agreed that the proposed approach would be the optimum way to utilize the best expertise available.

4.4.4.5 The meeting noted the challenges and benefits associated with the establishment of a new CAEP/9 MODTF remit to lead global discussions on aircraft noise modelling guidance, in close cooperation with WG1, SAE A-21 and AIRMOD. The meeting approved this task and requested the CAEP Secretary to include it in the list of tasks to be discussed under Agenda Item 5.

4.5 NOISE – OPERATIONS RELATED ISSUES

4.5.1 Initial assessment of the potential changes in Noise exposure associated with Steeper Approaches

4.5.1.1 The task group leader recalled that options for reducing approach noise are very limited. Increasing the height of the aircraft above ground by increasing the ILS glide path angle is one potential option.

4.5.1.2 ICAO had increased the preferred ILS glide path from 2.5 to 3 degrees in 1978. Where obstacle limitations prevent the use of a 3 degree glide path, higher angles are permitted; however, currently ICAO Doc 8168 PANS-OPS precludes the use of angle higher than 3 degrees solely for noise abatement reasons. At the first Steering Group of the CAEP/8 cycle, it was endorsed that the assessment should concentrate on approach angles below 4.5º. Since then, analysis has further narrowed to investigate steeper approach angles between 3 and 4º.

4.5.1.3 An initial report on the potential changes in noise exposure and fuel burn from steeper approaches was presented. In the future, additional factors such as local air quality (NO_x) could be included.

4.5.1.4 The analysis shows that once an aircraft has been slowed and configured during the initial and intermediate approach phases of flight, it is then possible to descend at an angle above 3º. It is recognized, however, that a steeper final approach segment may interfere with the practice of using reduced landing flap or delayed flap approach.

4.5.1.5 This analysis shows that there are noise benefits of the order of 0.5 dB per quarter degree increase in final approach angle, which is significant (7-8%) in terms of noise contours. Where the intermediate approach phase moved further out, greater noise benefits might be possible, but at the potential consequence of airport capacity and fuel burn. Thus, there is still significant optimisation and operational analysis to be undertaken.

4.5.1.6 A member presented a paper on possible adverse outcomes of such an initiative as such an initiative could increase the sensitivity to the same level of noise for people. Also, it was noted that in acoustic assessments, the general rule of thumb is that a change in noise of 3 dB(A) is on the threshold of perceptibility for a human. Thus, the projected benefits from the introduction of steeper approaches would be unlikely to be perceptible to almost all members of the community. The member therefore concluded that there could be a number of possible outcomes from the introduction of steeper approaches that could have either neutral or negative noise outcomes for members of the community.

4.5.1.7 An observer presented additional information noting that, according to PANS-OPS Part II, procedures involving glide paths greater than 3.5º are nominated as non-standard. Such non-standard procedures are not to be used as a means to introduce noise abatement procedures. Furthermore, a number of operational, safety and capacity concerns were raised in relation to this task which in his opinion made the task of identifying operational measures to reduce noise in the critical areas of final approach and landing difficult. It was highlighted that steeper final approach angles have many operational and safety implications for the flight execution and air traffic management. Besides these concerns, steeper approach may prove inefficient in terms of noise reduction and may cause more noise in other phases of flight. He suggested that a preliminary feasibility check from an operational perspective would be desirable before proceeding with the next round of environmental assessment.

Discussion and Conclusions

4.5.1.8 An observer noted that beyond 3.5^{o}, the analysis showed no additional benefit. He also noted that while the 80-90dB DNL contours were shown, the 55-65dB DNL contours were absent from the report. He also highlighted other related initiatives, such as the use of preferential runways, which are effective in reducing noise exposure. On the higher noise contours issue, the task group leader replied that these were chosen because of the close-in noise where the impact is the maximum. However, other noise contours could be explored if needed in future work.

4.5.1.9 Another observer and a member welcomed the work and appreciated the progress. They suggested that if environmental benefit is demonstrated, then operational assessment could be undertaken.

4.5.1.10 An officer of the Secretariat offered his assistance in taking this work further in the Operations Panel.

4.5.1.11 The task group leader clarified that operational and safety analysis would need to be undertaken by the relevant ICAO panels after an environmental assessment was completed and if an overall environmental benefit was proven.

4.5.1.12 Regarding possible adverse outcomes, a member asked whether CAEP should undertake experimental work monitoring the results to ascertain the possible benefit. The member, who presented the paper, replied that without any such future work, the benefits would remain uncertain.

4.5.1.13 A member appreciated the good work although noting his concern that in his experience, the noise can increase in the descent phase because of increased engine power. Another member added that because of such concerns, additional monitoring and modelling needs to be done probably covering more aircraft types.

4.5.1.14 A member appreciated the Operations Panel's offer of support and requested the meeting to accept the offer.

4.5.1.15 The Secretary stated the paramount importance of safety and that the involvement of operational expertise is in line with past practice and is a norm for CAEP, such as for the definition of noise abatement procedures. She reminded the meeting that all recommendations from CAEP go through ANC and any vetting from operational perspective can be directed and performed through existing procedures.

4.5.1.16 An observer also agreed that involvement of OPS Panel could be desirable at this stage.

4.5.1.17 A member expressed her preference to defer any additional CAEP work on the environmental benefit of steeper approaches until the relevant operational panels conduct an operational and safety assessment.

4.5.1.18 A member stated that the steeper approaches would have to be done by all the aircraft approaching a runway. This caused him concern because not all aircraft give similar benefit nor a benefit is assured for all aircraft. Therefore the member preferred deferral of future environmental work until operational work is completed. Another member agreed with this approach.

4.5.1.19 A member suggested that monitoring continue by any States interested in such work and when the technique and its results have matured, to bring it back to CAEP's attention.

4.5.1.20 The meeting agreed with the involvement of Operations Panel in line with past practice where CAEP and ANC have always cooperated very closely. The meeting further agreed to defer any additional CAEP work on the environmental benefit of steeper approaches until the relevant operational panels conduct an operational and safety assessment.

4.5.2 **Report on the Curfews Task**

4.5.2.1 Several members of the ICAO Council had raised several issues related to noise curfew during Council discussions. The task leader for the curfew study summarized some of these concerns as follows:

a) night curfews at some European airports are perceived to cause the transferring of their night time noise burden to some developing countries where night time noise is generated by aircraft scheduled to avoid departing or arriving during the curfew periods at European airports;

b) the need for continuing noise curfews has been questioned, given that aircraft noise Standards have improved over the years and the current aircraft in service are much quieter than when the curfews were instituted;

c) airports with night curfews that are capacity constrained during day time, restrict the ability to open up new slots for additional traffic which may result in opportunity costs to airlines and airports;

d) night curfews restrict the capability of airlines to offer flights at most convenient times (arrival or departure) to its customers, thereby reducing customer choice and adversely affecting airlines' level of service;

e) in the case of airports in developing countries that have excess capacity during day time, there may be additional economic costs of keeping the airport open during night-time which include air and ground crew, airport operations personnel, and general support staff; and

f) night curfews can cause inconvenience to passengers if they must arrive (or depart) at night time from one airport due to restrictions on departure (or arrival) airport.

4.5.2.2 He noted that WG2 is a technical issues group and therefore can only address environmental technical issues. For this reason, only the first item from the list above could be studied by the Working Group. This was also considered the most important specific issue raised by the ICAO Council and this assumption was confirmed by the ad hoc group participants from India and South Africa. The report, attached as Appendix C to the report on this agenda item, focuses on this aspect and also provides a review of the global extent of curfews.

4.5.2.3 The task leader presented a summary of the report on the environmental impacts of one region's airport curfews on other regions. The report contains details of the case studies for South Africa and India. Analysis was based on recent flight data of the study airports and the direct flights to and from European cities with curfews or night time flight restrictions.

4.5.2.4 The main conclusion drawn was that, while the European curfews may be a contributing factor to the generation of night time aircraft movements in some case study airports, there are probably a number of other influencing factors such as time zones, airline economics and passenger demand.

4.5.2.5 It was noted that discussions at the CAEP Steering Group 2009/3 meeting agreed with this conclusion and that the technical issues have now been fully addressed.

Discussion and Conclusions

4.5.2.6 In answer to a question from a member, the task leader clarified that European curfews **may be** a contributing factor to the generation of night time aircraft movements in some case study airports.

4.5.2.7 A member thanked the task leader and his observer organization for conducting this study and expressed his agreement with the results.

4.5.2.8 The meeting endorsed the Steering Group conclusion that the task has been completed.

4.5.3 Updates on the Balanced Approach

4.5.3.1 The WG1 Co-Rapporteur on behalf of the WG2 TG1 noted that the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829) was published by ICAO in 2004. The Balanced Approach encompasses four principle elements: reduction of noise at source, land-use planning and management, noise abatement operational procedures and operating restrictions. The application of the Balanced Approach requires careful assessment of all the different options and should be implemented on an airport-by-airport basis.

4.5.3.2 When developing ICAO Doc 9829, it was decided to add an appendix to include information concerning population/housing encroachment in the vicinity of airports. Encroachment around airports occurs when the population/housing grows in land near airports that has been relieved by aircraft-related noise reduction measures. Further development of that land can subsequently increase population exposed to noise and can lead to additional costs both to the community and aviation, if not coordinated with the airport's expansion plans.

4.5.3.3 Because of time limitations during CAEP/6, it was decided to delay this appendix, until the next CAEP cycle (CAEP/7). At CAEP/7, it was decided to continue the development of the Encroachment Appendix into the CAEP/8 work programme.

4.5.3.4 An Encroachment Appendix to the ICAO Doc 9829, Guidance on the Balanced Approach to Aircraft Noise Management was developed. It describes the findings from a limited number of States relative to assessments of population growth and encroachment around airports as a result of the effort completed during the CAEP/6 work programme. Since the original study was completed, more recent studies from various States (Brazil, Italy, New Zealand, and US) on encroachment analysis methodology at their airports were included. It provides an indication that encroachment has occurred and points to how the problem might be described and assessed in a systematic way. Assessing and quantifying encroachment requires that an airport maintain historical population data and housing information. The collected data provide indications of the possible means of quantifying encroachment and to control the land use management.

4.5.3.5 For States that have a formal definition of a noise protection zone, encroachment can be quantified by comparing the changes in population and housing within those zones over the selected time period. It was explained that the following elements are necessary in order to assess encroachment:

a) agree at local level on a reasonable reference contour or noise zone;

b) address capacity enhancements that can change over time, if considering planned ultimate capacity of airport; and

c) obtain historical population and housing data that track growth over time.

4.5.3.6 An observer presented a paper by WG2 that described a study developed for the European Commission (EC), *Study on Aircraft Noise Exposure at and around Community Airports: Evaluation on the Effects of Measures to Reduce Noise* [1] published in October 2007. The report was the product of a consultancy firm engaged by the European Commission to conduct a detailed analysis to establish how likely the European Community is to achieve its objective of limiting aircraft noise at and around Community airports under Directive 2002/30/EC, and to identify possible improvements to that legislation.

4.5.3.7 According to WG2, the study shows that some elements of the Balanced Approach have been used by European airports, but did not show that the Balanced Approach process as outlined in

[1] 'Study on aircraft noise exposure at and around Community airports: evaluation of the effects of measures to reduce noise' by MPD Group Limited, in association with Environment Resources Management and CE Delft, October 2007.

ICAO guidance is being systematically applied at the individual airport level. Rather, selective measures within the Balanced Approach have been implemented by a number of airports.

4.5.3.8 The report of WG2 highlighted that the main weaknesses of the EU Directive are the absences of requirements to define clearly the noise problem to be addressed, to evaluate in a systematic planning process the full array of available measures, and to weigh comparative cost-effectiveness of the full array of measures, and of any mandatory rule related to land-use planning, which is left to national, regional or even local authorities. The lack of harmonised guidelines and/or recommended best practice on land-use planning and management at the EU level affects both the effectiveness of the Directive and a correct implementation of the Balanced Approach.

4.5.3.9 An observer noted that the directive essentially relates to one part of the balanced approach, therefore the directive and the study cannot be used to evaluate the effectiveness of a complete implementation of the balanced approach.

4.5.3.10 The observer highlighted two principal conclusions from this study:

1) the impact of the directive was relatively limited – in part due to operating restrictions that were already in place; and

2) ambiguities were identified in the directive and the need for changes is presently under review.

4.5.3.11 The meeting noted that the new "Air Code of Ukraine" establishes the ICAO Balanced Approach as the basic mechanism of environmental protection activities for Ukrainian Civil Aviation.

Discussion and Conclusions

4.5.3.12 The meeting thanked the group for their continued work on the Balanced Approach and for the valuable information presented. It noted that the study conducted in response to directive 2002/30/EC was aimed at determining the effectiveness of the Directive and that it would not be reasonable to draw conclusions on the effectiveness of the balanced approach from this study alone.

4.5.3.13 A member noted there remain important differences of view with regard to the Directive's effectiveness in applying the Balanced Approach process across the EU, as described in the WG2 report, and explained that this issue is an important topic of discussion to be addressed in the bilateral services agreement between her State and the EU.

Recommendation

4.5.3.14 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 4/3 — Amendment to the *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829)

The *Guidance on the Balanced Approach to Aircraft Noise Management* (Doc 9829) be amended as indicated in Appendix D to the report on this agenda item.

4.5.4 **Management of Noise further out from Aerodromes**

4.5.4.1 The following five broad issues were covered in a report by WG2:

a) Noise in urban areas outside the noise contours;

b) Noise in the area between 9 and 12 km from the landing threshold;

c) Noise from en route aircraft;

d) Noise in "tranquil areas"; and

e) Noise/Emissions trade-offs.

4.5.4.2 The report identified a number of potential strategies for taking forward examination of each of the identified further out noise issues. However there was no consensus that further discussions fit into the CAEP priority areas identified at the 2009 Steering Group meeting and no specific tasks were identified for the future work programme.

4.5.4.3 The meeting noted that this work was not about close-in noise. The analysis of further out noise focused on where aircraft fly, how they are flown, how much respite between sound exposures there is, and level of community noise disclosure. CDO and similar procedures have greater effects on further out noise than they do on close-in noise. The group recommended including future work on this subject with CNS/ATM assessment activities.

Discussion and Conclusions

4.5.4.4 The meeting took note of these activities and noted that community noise issues include both close in and noise further away. The discussion of whether to include the assessment of further out noise in any CNS/ATM future analyses will be discussed under Agenda Item 5.

4.5.5 **Enhanced Description of the ICAO Environmental Goals**

4.5.5.1 WG2 recommended the following footnotes to accompany the relevant ICAO Goals:

Footnote 1

Conventionally 'significant aircraft noise' has been associated with areas subject to high noise exposure close to airports. Increasingly aircraft noise issues are arising from residents living in areas outside the contours used for land use planning purposes, notably for communities living under busy flight paths. Aircraft noise over designated 'tranquil areas' is also generating community concern in some countries. Recognition of these broader issues will provide more comprehensive responses to the management of aircraft noise.

Footnote 2

The aim of the Goals is to limit or reduce the impacts of aviation on the noise amenity of communities and on local air quality and climate change. However, these three issues are linked and strategies designed to minimise impacts in one of these areas may have adverse impacts on the others. For example, a Noise

Abatement Procedure may stipulate that aircraft fly around, rather than over, a particular community. The extra track miles involved in this procedure will have adverse climate change impacts and may have implications for local air quality. Understanding the trade-offs between the three elements when developing.

Discussion and Conclusions

4.5.5.2 The Secretary explained that the current ICAO environmental goals originated in CAEP and were the result of intense discussions. Together with the definition of the goals, a means to measure progress toward them had been identified. At this point, more discussion within CAEP is needed before the goals could be modified.

4.5.5.3 In particular, the Secretary explained that more work needs to be done within CAEP regarding interdependencies before they would be introduced as goals. She noted that CAEP is just beginning to understand how to quantify interdependencies.

4.5.5.4 The meeting recommended not to modify the goals, nor to add the proposed footnotes. In connection with this conclusion, a member pointed out that not every important issue can be quantified or data driven and that CAEP can also take decisions that are formed on a qualitative basis.

4.5.6 **Characterizing Noise further out from Aerodromes**

4.5.6.1 An observer explained that open rotor and supersonic Business jets might be noisier in climb, cruise, and descent compared to today's aircraft. Two small pilot studies were conducted by EASA on noise levels of aircraft in cruise and background noise levels as a result of little data being available on the subject.

4.5.6.2 Background research for the study identified that, as a rule of thumb, background noise is a function of population density. It was also determined that very little measured data exists for noise levels in quiet areas. The study included three primary activities:

1) Apply the "rule of thumb" to EU;

2) Measure ambient noise in quiet areas; and

3) Measure noise form aircraft in climb, cruise and descent.

4.5.6.3 For the study background noise was defined as L95 (noise level exceeded 95 per cent of the time). L95 is a function of population density except for an urban agglomeration, significant road traffic, or very low population density.

4.5.6.4 The study found that when aircraft are more than 2km away, no sound energy above 1000 Hz was measured. Therefore this frequency could be used to filter our bird noise. The analysis used ADS-B to match measured noise to aircraft, and the measurements were taken in low wind conditions. The meeting noted that the measured data is available for further study.

Discussion and Conclusions

4.5.6.5 A member noted that his State has conducted work similar to the EASA study, and had some different findings. He suggested that future work on noise during the climb, cruise, and descent phases may wish to consider the effects of the slope of climb/descent and bank angle.

4.5.7 **Review of Noise Abatement Procedure Research, Development and Implementation Projects**

4.5.7.1 An observer presented the WG2 report on its work of reviewing Noise Abatement Procedure Research, Development and Implementation Projects. He noted that the scope of this task was reduced by the Steering Group to eliminate the analysis of options or an evaluation of tradeoffs.

4.5.7.2 It was also noted that this task was a continuation of a similar work item from CAEP/7 that resulted in the publication of ICAO Document 9888, Review of Noise Abatement Procedure Research & Development and Implementation Results. It was therefore recommended that the document be updated to include the new information provided.

4.5.7.3 CAEP Memo 75 was issued on 10 November 2008 requesting specific information on Noise Abatement Procedure (NAP) Research, Development and Implementation (RD&I) projects. Seven responses were received describing 19 projects involving numerous States, Air Navigation Service Providers (ANSP's), airports, air carriers and manufacturers. A high-level summary report collating the submissions was provided.

4.5.7.4 The meeting noted that 15 of the 19 programmes for which information has been submitted utilize Continuous Descent Arrival (CDA) procedures, either wholly or in part, for noise reduction. Within the context of CDA, since the successful trials of CDA procedures at Stockholm-Arlanda and Louisville airports, efforts in Europe and the USA have been focussed on the wider implementation of CDA. By and large, these efforts have been restricted to low traffic operations. However, a number of programmes, specifically the Swedish Regional Advanced ATM Migration programme and the US GBAS TAP optimization programme seek to expand the use of CDA to higher traffic operations. These programmes, as well as the ECAC Advanced Mitigation Techniques programme, will develop precision approach procedures along noise preferential routes.

4.5.7.5 The observer explained that information was submitted on several international programmes, namely the ECAC Advanced Mitigation Techniques programme, the Atlantic Interoperability Initiative to Reduce Emissions (AIRE) and the Asia Pacific Interoperability Initiative to Reduce Emissions (ASPIRE). These programmes will leverage the work of previous or existing research programmes in order to facilitate the wider implementation of best practices that have been developed.

Discussion and Conclusions

4.5.7.6 Recalling the previous discussion on the effects of noise from the use of steeper approaches, an observer noted that many if not most potential noise source or operational noise advancements produce noise reductions less than 3dB. Meaningful noise changes are likely to come from a combination of improvements. If a threshold of 3dB were imposed for all improvements, whether operational or technical, many reduction endeavours would not be produced and it could therefore slow rate of innovation for technologies that could deliver true noise benefits. The observer suggested that it would not be appropriate for CAEP to set a noise benefit threshold and that as a technical committee all levels of noise reduction should be investigated by relying on the approach described in the balanced approach document.

4.5.7.7 A member reminded the meeting that the previous discussion about the perceptibility of noise changes of less than 3 dB was aimed specifically at the effects of the use of steeper approaches and was not in the context of technological changes.

4.5.7.8 The meeting congratulated WG2 on the consolidation of the material related to noise abatement procedures. The meeting concluded that no additional work is needed to complete task O.13 and that the action item is closed.

Recommendation

4.5.7.9 In light of the foregoing discussions the meeting developed the following recommendation:

Recommendation 4/4 — Amendment to the Review of Noise Abatement Procedure Research and Development and Implementation Results (Doc 9888)

The Review of Noise Abatement Procedure Research and Development and Implementation Results (Doc 9888) be updated with the information received by WG2.

— — — — — — — —

TEXT OF PROPOSED AMENDMENT TO THE

INTERNATIONAL STANDARDS
AND RECOMMENDED PRACTICES

ENVIRONMENTAL PROTECTION

ANNEX 16
TO THE CONVENTION ON INTERNATIONAL CIVIL AVIATION

VOLUME I
AIRCRAFT NOISE

. . .

PART I. DEFINITIONS

. . .

See Work Item N.16

Self-sustaining powered sailplane. A powered aeroplane with available engine power which allows it to maintain level flight but not to take off under its own power.

State of Design. The State having jurisdiction over the organization responsible for the type design.

Subsonic aeroplane. An aeroplane incapable of sustaining level flight at speeds exceeding flight Mach number of 1.

Type Certificate. A document issued by a Contracting State to define the design of an aircraft type and to certify that this design meets the appropriate airworthiness requirements of that State.

. . .

See Work Item N.16

PART II. AIRCRAFT NOISE CERTIFICATION

CHAPTER 1. ADMINISTRATION

. . .

1.10 ~~Unless otherwise specified in this volume of the Annex, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date of application submitted to the State of Design for a type certificate, or the date of application under an equivalent~~

~~prescribed procedure by the certificating authority of the State of Design. The application shall be effective for a duration equal to the period applied in the designation of the airworthiness regulations appropriate to the aircraft type, except in special cases where the certificating authority accepts an extension of this period.~~ The amendment of this volume of the Annex to be used by a Contracting State shall be that which is applicable on the date of submission to that Contracting State for:

a) a Type Certificate in the case of a new type; or

b) approval of a change in type design in the case of a derived version; or

c) in either case, under an equivalent application procedure prescribed by the certificating authority of that Contracting State.

Note.— As each new edition and amendment of this Annex becomes applicable (according to Table A of the Foreword) it supersedes all previous editions and amendments.

1.11 ~~When this period of effectivity is exceeded, the date to be used in determining the applicability of the Standards in this Annex shall be the date of issue of the type certificate, or the date of issue of approval under an equivalent prescribed procedure, less the duration of effectivity.~~ Unless otherwise specified in this volume of the Annex, the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date the application for a Type Certificate was submitted to the State of Design, or the date of submission under an equivalent application procedure prescribed by the certificating authority of the State of Design.

1.12 For derived versions where the provisions governing the applicability of the Standards of this Annex refer to "the application for the certification of the change in type design", the date to be used by Contracting States in determining the applicability of the Standards in this Annex shall be the date the application for the change in type design was submitted to the Contracting State that first certified the change in type design, or the date of submission under an equivalent application procedure prescribed by the certificating authority of the Contracting State that first certified the change in type design.

Note 1. — Unless otherwise specified in this volume of the Annex the edition of Doc 9501, Volume I, to be used as guidance on the use of acceptable means of compliance and equivalent procedures by a Contracting State should be that which is in effect on the date the application for a type certificate or the change in type design is submitted to that Contracting State.

Note 2. — The means of compliance and the use of equivalent procedures are subject to the acceptance of the certificating authority of the Contracting State.

1.13 An application shall be effective for the period specified in the designation of the airworthiness regulations appropriate to the aircraft type, except in special cases where the certificating authority accepts an extension of this period. When this period of effectivity is exceeded, the date to be used in determining the applicability of the Standards in this Annex shall be the date of issue of the Type Certificate or approval of the change in type design, or the date of issue of approval under an equivalent procedure prescribed by the State of Design, less the period of effectivity.

. . .

See Work Items N.16 and N.21

CHAPTER 2. SUBSONIC JET AEROPLANES — ~~APPLICATION FOR TYPE CERTIFICATE SUBMITTED BEFORE 6 OCTOBER 1977~~Application for type certificate submitted before 6 October 1977

2.1 Applicability

Note.— See also Chapter 1, 1.10 ~~and~~ 1.11, 1.12 and 1.13.

2.1.1 The Standards of this chapter shall be applicable to all subsonic jet aeroplanes for which ~~either~~ the application for a Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ before 6 October 1977, except those aeroplanes:

a) requiring a runway length[1] of 610 m or less at maximum certificated mass for airworthiness; or

b) powered by engines with a bypass ratio of 2 or more and for which a certificate of airworthiness for the individual aeroplane was first issued before 1 March 1972; or

c) powered by engines with a bypass ratio of less than 2 and for which ~~either~~ the application for a Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ before 1 January 1969, and for which a certificate of airworthiness for the individual aeroplane was first issued before 1 January 1976.

2.1.2 ~~The Standards of this chapter shall also be applicable to~~ The maximum noise levels of 2.4.1 shall apply except for derived versions ~~of all aeroplanes covered by 2.1.1~~ for which the application for certification of ~~a~~ the change in type design was ~~accepted, or another equivalent procedure was carried out by the certificating authority,~~ submitted on or after 26 November 1981, in which case the maximum noise levels of 2.4.2 shall apply.

. . .

2.6 Test procedures

. . .

2.6.2 Approach test procedure

2.6.2.1 The aeroplane shall be stabilized and following a 3° ± 0.5° glide path.

2.6.2.2 The approach shall be made at a stabilized airspeed of not less than 1.3 V_S + 19 km/h (1.3 V_S + 10 kt) with thrust stabilized during approach and over the measuring point and continued to a normal touchdown.

2.6.2.3 The configuration of the aeroplane shall be with maximum allowable landing flap setting.

Note.— Guidance material on the use of equivalent procedures is provided in ~~the~~ ~~Environmental~~

1. With no stopway or clearway.

Technical Manual on the Use of Procedures in the Noise Certification of Aircraft (*Doc 9501, Volume I*).

. . .

See Work Items N. 15, N. 16, N. 18 and N. 21

CHAPTER 3.

1.— SUBSONIC JET AEROPLANES — Application for Type Certificate submitted on or after 6 October 1977 and before 1 January 2006

2.— PROPELLER-DRIVEN AEROPLANES OVER 5 7008 618 kg — Application for Type Certificate submitted on or after 1 January 1985 and before 17 November 1988 1 January 2006

3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate submitted on or after 17 November 1988 and before 1 January 2006

3.1 Applicability

Note 1.— See also Chapter 1, 1.10 and, 1.11, 1.12 and 1.13.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

3.1.1 The Standards of this chapter shall, with the exception of those propeller-driven aeroplanes specifically designed and used for agricultural or fire-fighting purposes, be applicable to:

a) all subsonic jet aeroplanes, including their derived versions, other than aeroplanes which require a runway[1] length of 610 m or less at maximum certificated mass for airworthiness, in respect of for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977 and before 1 January 2006;

b) all propeller-driven aeroplanes, including their derived versions, of over 5 700 8 618 kg maximum certificated take-off mass (except those described in Chapter 6, 6.1), for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985 and before 17 November 1988, except where the Standards of Chapter 10 apply; and1 January 2006.

c) all propeller-driven aeroplanes, including their derived versions, of over 8 618 kg maximum certificated take-off mass, for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988 and before 1 January 2006.

. . .

3.3 Noise measurement points

3.3.1 Reference noise measurement points

An aeroplane, when tested in accordance with these Standards, shall not exceed the noise levels specified in 3.4 at the following points:

a) *lateral full-power reference noise measurement point*

. . .

Note.— For aeroplanes specified in 3.1.1 b) ~~and for aeroplanes specified in 3.1.1 c)~~ for which the application for a ~~certificate of airworthiness for the prototype~~ type certificate was ~~accepted~~ submitted before 19 March 2002, the lateral noise requirement specified in 3.3.1 a) 1) is permitted as an alternative.

. . .

3.6 Noise certification reference procedures

. . .

3.6.2 Take-off reference procedure

Take-off reference flight path shall be calculated as follows:

. . .

d) the speed shall be: ~~the all-engines operating take-off climb speed selected by the applicant for use in normal operation, which shall be at least V_2 + 19 km/h (V_2 + 10 kt) but not greater than V_2 + 37 km/h (V_2 + 20 kt) and which shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test. The increment applied to V_2 shall be the same for all reference masses of an aeroplane model unless a difference in increment is substantiated based on performance characteristics of the aeroplane;~~

1) for those aeroplanes for which the applicable airworthiness requirements define V2, the all engines operating take-off climb speed selected by the applicant for use in normal operation, which shall be at least V2 + 19 km/h (V2 + 10 kt) but not greater than V2 + 37 km/h (V2 + 20 kt) and which shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test. The increment applied to V2 shall be the same for all reference masses of an aeroplane model unless a difference in increment is substantiated based on performance characteristics of the aeroplane.

Note.— V2 is defined in accordance with the applicable airworthiness requirements.

2) for those aeroplanes for which the applicable airworthiness requirements do not define V2, the take-off speed at 15 m (50 ft) plus an increment of at least 19 km/h (10 kt) but not greater than 37 km/h (20 kt), or the minimum climb speed, whichever speed is greater. This speed shall be attained as soon as practicable after lift-off and be maintained throughout the take-off noise certification test.

Note.— Take-off speed at 15 m (50 ft) and minimum climb speed are defined in accordance with the applicable airworthiness requirements;

. . .

3.7 Test procedures

. . .

3.7.3 Acoustic data shall be adjusted by the methods outlined in Appendix 2 to the reference conditions specified in this chapter. Adjustments for speed and thrust shall be made as described in Section ~~9~~ 8 of Appendix 2.

. . .

3.7.6 If equivalent test procedures different from the reference procedures are used, the test procedures and all methods for adjusting the results to the reference procedures shall be approved by the certificating authority. The amounts of the adjustments shall not exceed 16 EPNdB on take-off and 8 EPNdB on approach, and if the adjustments are more than 8 EPNdB and 4 EPNdB, respectively, the resulting numbers shall be more than 2 EPNdB below the noise limits specified in 3.4.

Note.— Guidance material on the use of equivalent procedures is provided in ~~*the* Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft (~~*Doc 9501, Volume I*~~)~~.

See Work Items N.16 and N.21

CHAPTER 4.

1.— SUBSONIC JET AEROPLANES — Application for Type Certificate submitted on or after 1 January 2006

2.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate submitted on or after 1 January 2006

4.1 Applicability

Note. — See also Chapter 1, 1.10, ~~*and*~~ *1.11, 1.12 and 1.13.*

4.1.1 The Standards of this chapter shall, with the exception of those propeller-driven aeroplanes specifically designed and used for agricultural or fire-fighting purposes, be applicable to:

a) all subsonic jet aeroplanes, including their derived versions, other than aeroplanes which require a runway[1] length of 610 m or less at maximum certificated mass for airworthiness~~, in respect of~~ for which ~~either~~ the application for a Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ on or after 1 January 2006;

b) all propeller-driven aeroplanes, including their derived versions, of over 8 618 kg maximum certificated take-off mass, for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 2006; and

c) all subsonic jet aeroplanes and all propeller-driven aeroplanes certificated originally as satisfying Annex 16, Volume 1, Chapter 3 or Chapter 5, for which recertification to Chapter 4 is requested.

Note.— Guidance material on applications for recertification is provided in the Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft *(Doc 9501, Volume I)*.

See Work Items N.15, N.16 and N.21

CHAPTER 5. PROPELLER-DRIVEN AEROPLANES OVER 5 700 8 618 kg — APPLICATION FOR TYPE CERTIFICATE SUBMITTED BEFORE 1 JANUARY 1985 Application for Type Certificate submitted before 1 January 1985

5.1 Applicability

Note 1.— See also Chapter 1, 1.10, and 1.11, 1.12 and 1.13.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

5.1.1 The Standards defined hereunder are not applicable to:

a) aeroplanes requiring a runway[1] length of 610 m or less at maximum certificated mass for airworthiness;

b) aeroplanes specifically designed and used for fire fighting purposes;

c) aeroplanes specifically designed and used for agricultural purposes;.

d) aeroplanes to which the Standards of Chapter 6 apply; and

e) aeroplanes to which the Standards of Chapter 10 apply.

5.1.2 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 8 618 kg maximum certificated take-off mass for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 6 October 1977 and before 1 January 1985.

5.1.3 The Standards of Chapter 2, with the exception of Sections 2.1 and 2.4.2, shall be applicable to derived versions and individual propeller-driven aeroplanes of over 5 700 8 618 kg maximum certificated take-off mass and to which Standards of Chapter 6 do not apply and are of the type for which the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 6 October 1977, and which are either:

a) derived versions for which the application for certification of the change in type design was submitted on or after 6 October 1977; or

b) individual aeroplanes for which a certificate of airworthiness for the individual aeroplane was first issued on or after 26 November 1981.

5.1.4 The Standards of Chapter 3, with the exception of Section 3.1, shall be applicable to all propeller-driven aeroplanes, including their derived versions, of over 5 700 kg maximum take-off mass, for which either the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985.

. . .

5.7 Test procedures

. . .

5.7.3 Acoustic data shall be adjusted by the methods outlined in Appendix 2 to the reference conditions specified in this chapter. Adjustments for speed and thrust shall be made as described in Section 9 8 of Appendix 2.

. . .

5.7.6 If equivalent test procedures different from the reference procedures are used, the test procedures and all methods for adjusting the results to the reference procedures shall be approved by the certificating authority. The amounts of the adjustments shall not exceed 16 EPNdB on take-off and 8 EPNdB on approach, and if the adjustments are more than 8 EPNdB and 4 EPNdB, respectively, the resulting numbers shall not be within 2 EPNdB of the limit noise levels specified in 5.4.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft *(Doc 9501, Volume I).*

See Work Items N.16 and N.21

CHAPTER 6. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE SUBMITTED BEFORE 17 NOVEMBER 1988 Application for Type Certificate submitted before 17 November 1988

6.1 Applicability

Note 1.— See also Chapter 1, 1.10, and 1.11, 1.12 and 1.13.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

The Standards of this chapter shall be applicable to all propeller-driven aeroplanes, except those aeroplanes specifically designed and used for aerobatic purposes or, agricultural or fire fighting uses purposes, of having a maximum certificated take-off mass not exceeding 8 618 kg for which either:

a) the application for the Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1975 and before 17 November 1988, except for derived versions for which an the application for a Type Certificate certification of the change in type design was submitted, or another equivalent procedure was carried out by the certificating authority, on or after 17 November 1988, in which case the Standards of Chapter 10 apply; or

b) a certificate of airworthiness for the individual aeroplane was first issued on or after 1 January 1980.

. . .

6.5 Test procedures

. . .

6.5.3 Overflight shall be performed at the highest power in the normal operating range,[2] stabilized airspeed and with the aeroplane in the cruise configuration.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft *(Doc 9501, Volume I).*

See Work Items N.16 and N.21

CHAPTER 8. HELICOPTERS

8.1 Applicability

Note.— See also Chapter 1, 1.10, and 1.11, 1.12 and 1.13.

8.1.1 The Standards of this chapter shall be applicable to all helicopters for which 8.1.2, 8.1.3, and 8.1.4 apply, except those designed exclusively specifically designed and used for agricultural, fire fighting or external load carrying purposes.

8.1.2 For a helicopter for which the application for the Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1985, except for those helicopters specified in 8.1.4, the maximum noise levels of 8.4.1 shall apply.

8.1.3 For a derived version of a helicopter for which the application for a certification of the change of in type design was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988, except for those helicopters specified in 8.1.4, the maximum noise levels of 8.4.1 shall apply.

8.1.4 For all helicopters, including their derived versions, for which the application for the Type

Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 21 March 2002, the maximum noise levels of 8.4.2 shall apply.

. . .

8.7 Test procedures

. . .

8.7.11 Tests shall be conducted at a helicopter mass not less than 90 per cent of the relevant maximum certificated mass and may be conducted at a mass not exceeding 105 per cent of the relevant maximum certificated mass. For each of the three flight conditions, at least one test must be completed at or above this maximum certificated mass.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft *(Doc 9501, Volume I).*

. . .

See Work Items N. 16 and N. 21

CHAPTER 10. PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — APPLICATION FOR TYPE CERTIFICATE OR DERIVED VERSION SUBMITTED ON OR AFTER 17 NOVEMBER 1988 Application for Type Certificate or Derived Version submitted on or after 17 November 1988

10.1 Applicability

Note 1.— See also Chapter 1, 1.10, and 1.11, 1.12 and 1.13.

Note 2.— See Attachment E for guidance on interpretation of these applicability provisions.

10.1.1 The Standards of this chapter shall be applicable to all propeller-driven aeroplanes and their derived versions, with a certificated take-off mass not exceeding 8 618 kg, except those aeroplanes specifically designed and used for aerobatic purposes and , agricultural or fire fighting uses purposes and self-sustaining powered sailplanes.

10.1.2 For an aeroplane aeroplanes for which the application for the Type Certificate or for all derived versions was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 17 November 1988, except for those aeroplanes specified in 10.1.4 10.1.6, the maximum noise limits levels of 10.4 a) shall apply.

10.1.3 For aeroplanes specified in 10.1.2 which fail to comply with the Standards of this chapter and where the application for the Type Certificate or all derived versions was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, before 17 November 1993, and which fail to comply with the Standards of this chapter the Standards of Chapter 6 shall apply.

10.1.4 For single-engined aeroplanes, except those aeroplanes specifically designed for aerobatic purposes and agricultural or fire fighting uses, self-sustaining powered sailplanes, float planes and amphibians, for which: For derived versions for which the application for certification of the change in type design was submitted on or after 17 November 1988, except for those derived versions specified in 10.1.6, the maximum noise levels of 10.4 a) shall apply.

a) the application for the Type Certificate or their derived versions was submitted, or another equivalent procedure was carried out by the certificating authority, on or after 4 November 1999, the noise limits of 10.4 b) shall apply;

b) an application for the Type Certificate for the derived version was submitted, or other procedure was carried out, on or after 4 November 1999, but for which the application for the Type Certificate, or another equivalent procedure was carried out by the certificating authority, before 4 November 1999, the noise limits of 10.4 b) shall apply;

c) the requirements of b) above apply, but which fail to meet the noise limits of 10.4 b), the noise limits of 10.4 a) shall apply provided that the application for the derived version was made before 4 November 2004.

10.1.5 For derived versions specified in 10.1.4 where the application for certification of the change in type design was submitted before 17 November 1993 and which fail to comply with the Standards of this chapter the Standards of Chapter 6 shall apply.

10.1.6 For single-engined aeroplanes, except float planes and amphibians:

a) the maximum noise levels of 10.4 b) shall apply to those aeroplanes, including their derived versions, for which the application for the Type Certificate was submitted on or after 4 November 1999;

b) the maximum noise levels of 10.4 b) shall apply to those derived versions of aeroplanes for which the application for the Type Certificate was submitted before 4 November 1999 and for which the application for certification of the change in type design was submitted on or after 4 November 1999; except

c) for those derived versions described in 10.1.6 b) where the application for certification of the change in type design was submitted before 4 November 2004 and which exceed the maximum noise levels of 10.4 b), in which case the maximum noise levels of 10.4 a) shall apply.

. . .

10.6 Test procedures

. . .

10.6.4 If equivalent test procedures are used, the test procedures and all methods for correcting the results to the reference procedures shall be approved by the certificating authority.

Note.— Guidance material on the use of equivalent procedures is provided in the Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft *(Doc 9501, Volume I).*

See Work Items N. 16 and N. 21

CHAPTER 11. HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

11.1 Applicability

Note.— See also Chapter 1, 1.10, ~~and~~ 1.11, 1.12 and 1.13.

11.1.1 The Standards of this chapter shall be applicable to all helicopters having a maximum certificated take-off mass not exceeding 3 175 kg for which 11.1.2, 11.1.3 and 11.1.4 apply, except those specifically designed ~~exclusively~~ and used for agricultural, fire fighting or external load carrying purposes.

11.1.2 For a helicopter for which the application for the Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ on or after 11 November 1993, except for those helicopters specified in 11.1.4, the maximum noise levels of 11.4.1 shall apply.

11.1.3 For a derived version of a helicopter for which the application for ~~the Type Certificate for a~~ certification of the change ~~of~~ in type design was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ on or after 11 November 1993, except for those helicopters specified in 11.1.4, the maximum noise levels of 11.4.1 shall apply.

11.1.4 For all helicopters, including their derived versions, for which the application for the Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ on or after 21 March 2002, the maximum noise levels of 11.4.2 shall apply.

. . .

11.6 Test procedures

. . .

11.6.9 Tests shall be conducted at a helicopter mass not less than 90 per cent of the relevant maximum certificated mass and may be conducted at a mass not exceeding 105 per cent of the relevant maximum certificated mass.

Note.— Guidance material on the use of equivalent procedures is provided in ~~the~~ ~~Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft~~ *~~(~~Doc 9501, Volume I~~)~~.*

See Work Items N. 6 and N. 16

CHAPTER 12. SUPERSONIC AEROPLANES

12.1 Supersonic aeroplanes ~~— application~~ Application for Type Certificate submitted before 1 January 1975

12.1.1 The Standards of Chapter 2 of this Part, with the exception of the maximum noise levels specified in 2.4, shall be applicable to all supersonic aeroplanes, including their derived versions, ~~in respect of~~ for which ~~either~~ the application for the Type Certificate was submitted~~, or another equivalent prescribed procedure was carried out by the certificating authority,~~ before 1 January 1975, and for which a certificate of airworthiness for the individual aeroplane was first issued after 26 November 1981.

12.1.2 The maximum noise levels of those aeroplanes covered by 12.1.1, when determined in accordance with the noise evaluation method of Appendix 1, shall not exceed the measured noise levels of the first certificated aeroplane of the type.

12.2 Supersonic aeroplanes — ~~application~~ Application for Type Certificate submitted on or after 1 January 1975

Note.— Standards and Recommended Practices for these aeroplanes ~~are not yet developed but the noise levels of Chapter 3 of this Part applicable to subsonic jet aeroplanes may be used as guidelines for aeroplanes for which the application for a Type Certificate was submitted, or another equivalent prescribed procedure was carried out by the certificating authority, on or after 1 January 1975~~ have not been developed. However, the maximum noise levels of the part that would be applicable to subsonic jet aeroplanes may be used as a guideline. Acceptable levels of sonic boom have not been established and compliance with subsonic noise Standards may not be presumed to permit supersonic flight.

. . .

See Work Items N. 16 and N. 21

APPENDIX 1. EVALUATION METHOD FOR NOISE CERTIFICATION OF SUBSONIC JET AEROPLANES — ~~APPLICATION FOR TYPE CERTIFICATE SUBMITTED BEFORE 6 OCTOBER 1977~~ Application for Type Certificate submitted before 6 October 1977

. . .

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

This section prescribes the conditions under which noise certification tests shall be conducted and the measurement procedures that shall be used.

Note.— Many applications for a noise certificate involve only minor changes to the aeroplane type design. The resultant changes in noise can often be established reliably without the necessity of resorting to a complete test as outlined in this appendix. For this reason certificating authorities are encouraged to permit the use of appropriate "equivalent procedures". Also, there are equivalent procedures that may be used in full certification tests, in the interest of reducing costs and providing reliable results. Guidance *material on the use of equivalent procedures in the noise certification of subsonic jet aeroplanes is provided in ~~the~~* ~~Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft~~ ~~(~~*Doc 9501, Volume I*~~)~~.

. . .

See Work Item N. 16

APPENDIX 2. EVALUATION METHOD FOR NOISE CERTIFICATION OF:

1.— SUBSONIC JET AEROPLANES — Application for Type Certificate submitted on or after 6 October 1977

2.— PROPELLER-DRIVEN AEROPLANES OVER ~~5 700~~ 8 618 kg — Application for Type Certificate submitted on or after 1 January 1985 ~~and before 17 November 1988~~

~~**3.— PROPELLER-DRIVEN AEROPLANES OVER 8 618 kg — Application for Type Certificate submitted on or after 17 November 1988**~~

~~4~~3.— HELICOPTERS

. . .

See Work Items N. 15 and N. 21

1. INTRODUCTION

. . .

Note 3.— A complete list of symbols and units, the mathematical formulation of perceived noisiness, a procedure for determining atmospheric attenuation of sound, and detailed procedures for correcting noise levels from non-reference to reference conditions are included in Sections 6 to ~~9~~ 8 of this appendix.

2. NOISE CERTIFICATION TEST AND MEASUREMENT CONDITIONS

2.1 General

This section prescribes the conditions under which noise certification tests shall be conducted and the measurement procedures that shall be used.

Note.— Many applications for a noise certificate involve only minor changes to the aircraft type design. The resultant changes in noise can often be established reliably without the necessity of resorting to a *complete test as outlined in this appendix. For this reason certificating authorities are encouraged to permit the use of appropriate "equivalent procedures". Also, there are equivalent procedures that may be used in full certification tests, in the interest of reducing costs and providing reliable results. Guidance material on the use of equivalent procedures in the noise certification of subsonic jet and propeller-driven aeroplanes and helicopters is provided in* ~~*the* Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft (~~*Doc 9501, Volume I*~~)~~.

. . .

2.2.2 Atmospheric conditions

2.2.2.1 ~~*Specifications*~~ *Definitions and specifications*

. . .

Maximum wind speed. The maximum value within the series of individual wind speed samples recorded every second over a period that spans the 10 dB-down time interval.

Sound attenuation coefficient. The reduction in level of sound within a one-third octave band, in dB per 100 meters, due to the effects of atmospheric absorption of sound. Equations for the calculation of sound attenuation coefficients from values of atmospheric temperature and relative humidity are provided in Section 7.

. . .

Replace Sections 2.2.2.2 through 2.2.2.6 as follows:

2.2.2.2 *Measurement*

2.2.2.2.1 Measurements of the ambient temperature and relative humidity shall be made at 10 m (33 ft) above the ground. For aeroplanes the ambient temperature and relative humidity shall also be determined at vertical increments not greater than 30 m (100 ft) over the sound propagation path. For an aircraft test run to be acceptable, measurements of ambient temperature and relative humidity shall be obtained before and after the test run. Both measurements shall be representative of the prevailing conditions during the test run and at least one of the measurements of ambient temperature and relative humidity shall be within 30 minutes of the test run. The temperature and relative humidity data at the actual time of the test run shall be interpolated over time and height, as necessary, from the measured meteorological data.

Note 1.— The temperature and relative humidity measured at 10 m (33 ft) are assumed to be constant from 10 m (33 ft) to the ground.

2.2.2.2.2 Measurements of wind speed and direction shall be made at 10 m (33 ft) above the ground throughout each test run.

2.2.2.2.3 The meteorological conditions at 10 m above the ground shall be measured within 2 000 m (6 562 ft) of the microphone locations. They shall be representative of the conditions existing over the geographical area in which noise measurements are made.

2.2.2.3 *Instrumentation*

2.2.2.3.1 Instrumentation for the measurement of temperature and humidity between the ground and the aeroplane, including instrumentation for the determination of the height at which these measurements are made, and the manner in which such instrumentation is used shall, to the satisfaction of the certificating authority, enable the sampling of atmospheric conditions at 30 m (100 ft) vertical height increments or less.

2.2.2.3.2 All wind speed samples shall be taken with the sensor installed such that the horizontal distance between the anemometer and any obstruction is at least 10 times the height of the obstruction. Installation error for the wind direction sensor shall be no greater than 5 degrees.

2.2.2.3.3 The instrumentation for noise and meteorological measuring and aircraft flight path tracking shall be operated within the environmental limitations specified by the manufacturer.

2.2.2.4 *Test window*

2.2.2.4.1 For aircraft test runs to be acceptable they shall be carried out under the following atmospheric conditions, except as provided in 2.2.2.4.2:

a) there shall be no precipitation;

b) the ambient air temperature shall not be greater than 35°C and shall not be less than -10°C over the sound propagation path between a point 10 m (33 ft) above the ground and the aircraft;

c) the relative humidity shall not be greater than 95 per cent and shall not be less than 20 per cent over the sound propagation path between a point 10 m (33 ft) above the ground and the aircraft;

d) the sound attenuation coefficient in the 8 kHz one-third octave band shall not be more than 12 dB/100 m over the sound propagation path between a point 10 m (33 ft) above the ground and the height of the aircraft at PNLTM;

Note.— Section 7 of this appendix specifies the method for calculation of sound attenuation coefficients based on temperature and humidity.

e) for aeroplanes the average wind speed at 10 m (33 ft) above the ground shall not exceed 22 km/h (12 kt) and the maximum wind speed at 10 m (33 ft) above the ground shall not exceed 28 km/h (15 kt);

f) for aeroplanes the average cross-wind component at 10 m (33 ft) above the ground shall not exceed 13 km/h (7 kt) and the maximum cross-wind component at 10 m (33 ft) above the ground shall not exceed 18 km/h (10 kt);

g) for helicopters the average wind speed at 10 m (33 ft) above the ground shall not exceed 19 km/h (10 kt);

h) for helicopters the average cross-wind component at 10 m (33 ft) above the ground shall not exceed 9 km/h (5 kt);

i) there shall be no anomalous meteorological or wind conditions that would significantly affect the measured noise levels.

2.2.2.4.2 For helicopters the requirements of 2.2.2.4.1 b), c) and d) shall only apply at 10 m (33 ft) above the ground.

2.2.2.5 *Layering*

2.2.2.5.1 For each aeroplane test run the sound attenuation coefficient in the 3150 Hz one-third octave band, shall be determined at the time of PNLTM from 10 m (33 ft) above the ground to the height of the aeroplane, with vertical height increments not greater than 30 m (100 ft).

2.2.2.5.2 If the individual values of the sound attenuation coefficient in the 3150 Hz one-third octave band associated with the vertical height increments specified in 2.2.2.5.1 do not vary by more than 0.5 dB/100m relative to the value determined at 10 m (33 ft), the coefficient to be used in the adjustment of the aeroplane noise levels for each one-third octave band shall be the average of the coefficient calculated from the temperature and humidity at 10 m (33 ft) above the ground and the coefficient calculated from the temperature and humidity at the height of the test aeroplane.

2.2.2.5.3 If the individual values of the sound attenuation coefficient in the 3150 Hz one-third octave band associated with the vertical height increments specified in 2.2.2.5.1 vary by more than 0.5 dB/100 m relative to the value determined at 10 m (33 ft), then “layered” sections of the atmosphere shall be used, as described below, in the computation of the coefficient for each one-third octave band to be used in the adjustment of the aeroplane noise levels:

a) the atmosphere from the ground to at least the height of the aeroplane shall be divided into layers of 30 m (100 ft) depth;

b) for each of the layers specified in 2.2.2.5.3 a), the sound attenuation coefficient shall be determined for each one-third octave band;

c) for each one-third octave band the sound attenuation coefficient to be used in the adjustment of the aeroplane noise levels shall be the average of the individual layer coefficients specified in 2.2.2.5.3 b).

2.2.2.5.4 For helicopters, the sound attenuation coefficient to be used in the adjustment of noise levels for each one-third octave band shall be calculated from the temperature and humidity at 10 m (33 ft) above the ground.

See Work Items N. 15 and N. 21

2.3 Flight path measurement

. . .

2.3.3 Position and performance data required to make the adjustments referred to in Section 8 ~~or 9~~ of this appendix shall be automatically recorded at an approved sampling rate. Measuring equipment shall be approved by the certificating authority.

. . .

3. MEASUREMENT OF AIRCRAFT NOISE RECEIVED ON THE GROUND

. . .

3.10 Adjustments for background noise

3.10.1 Background noise shall be recorded (for at least 30 seconds) at the measurement points with the system gain set at the levels used for the aircraft noise measurements. The recorded background noise sample shall be representative of that which exists during the test run. The recorded aircraft noise data shall be accepted only if the background noise levels, when analysed in the same way and quoted in PNL (see 4.1.3 a)), are at least 20 dB below the maximum PNL of the aircraft.

3.10.2 Aircraft sound pressure levels within the 10 dB-down points (see 4.5.1) shall exceed mean background noise levels determined above by at least 3 dB in each one-third octave band or be adjusted using a method similar to that described in ~~Appendix 3~~ *the section* of Doc 9501, *Volume I concerning the adjustment of aircraft noise levels for the effect of background noise*.

4. CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL FROM MEASURED NOISE DATA

4.1 General

Replace Section 4.1 as follows:

4.1.1 The metric used to quantify the certificated noise level shall be the effective perceived noise level (EPNL) expressed in units of EPNdB. EPNL is a single number evaluator taking into account the subjective effects of aircraft noise on human beings. It consists of the instantaneous perceived noise level, PNL, adjusted for spectral irregularities and for duration.

4.1.2 In order to derive the EPNL, three basic physical properties of the aircraft noise shall be measured: level, frequency distribution, and variation over time. This requires the acquisition of the instantaneous sound pressure levels in spectra composed of 24 one-third octave bands, which shall be obtained for each one-half second increment of time throughout the duration over which the aircraft noise is measured.

4.1.3 The calculation procedure which utilizes physical measurements of noise to derive the EPNL evaluation measure of subjective response shall consist of the five following steps:

a) each of the 24 one-third octave band sound pressure levels in each measured one-half second spectrum is converted to perceived noisiness by the method of Section 4.7. The noy values are combined and then converted to instantaneous perceived noise level, PNL(k) for each spectrum, measured at the k^{th} instant of time, by the method of Section 4.2;

b) for each spectrum a tone correction factor, C(k), is calculated by the method of Section 4.3 to account for the subjective response to the presence of spectral irregularities;

c) the tone correction factor is added to the perceived noise level to obtain the tone corrected perceived noise level, PNLT(k), for each spectrum:

$$PNLT(k) = PNL(k) + C(k);$$

d) the history of PNLT(k) noise levels is examined to identify the maximum value, PNLTM as determined by the method of Section 4.4, and noise duration as determined by the method of Section 4.5; and

e) effective perceived noise level, EPNL, is determined by logarithmic summation of the PNLT levels over the noise duration, and normalizing the duration to 10 seconds, by the method of Section 4.6.

See Work Items N. 15 and N. 21

4.2 Perceived noise level

Instantaneous perceived noise levels, PNL(k), shall be calculated from instantaneous one-third octave band sound pressure levels, SPL(i,k), as follows:

Step 1. Convert each one-third octave band, SPL(i,k), from 50 to 10 000 Hz, to perceived noisiness, $n(i,k)$, by reference to ~~Table A4-1 (Perceived Noisiness) in Appendix 4 of Doc 9501, or to~~ the mathematical formulation of ~~the~~ noy ~~table~~ tables given in Section 4.7 or to the section in Doc 9501, Volume I concerning reference tables used in the manual calculation of effective perceived noise level.

. . .

Step 3. Convert the total perceived noisiness, $N(k)$, into perceived noise level, PNL(k), by the following formula:

. . .

Note.— Perceived noise level, PNL(k)*, as a function of total perceived noisiness is plotted in ~~Figure A4-1 of Appendix 4~~ Section 2.6 of Doc 9501, Volume I concerning reference tables used in the manual calculation of effective perceived noise level.*

4.3 Correction for spectral irregularities

4.3.1 Noise having pronounced spectral irregularities (for example, the maximum discrete frequency components or tones) shall be adjusted by the correction factor, $C(k)$, calculated as follows:

. . .

Step 10. Designate the largest of the tone correction factors, determined in Step 9, as $C(k)$. An example of the tone correction procedure is given in ~~Table A4-2 of Appendix 4~~ the section of Doc 9501, Volume I concerning reference tables used in the manual calculation of effective perceived noise level.

. . .

4.4 Maximum tone corrected perceived noise level

Replace Sections 4.4 through 4.6 as follows:

4.4.1 The tone corrected perceived noise levels, PNLT(k), are calculated from measured one-half second values of SPL in accordance with the procedure of Section 4.3. The maximum tone corrected perceived noise level, PNLTM, shall be the maximum value of PNLT(k), adjusted if necessary for the presence of bandsharing by the method of Section 4.4.2. The increment associated with PNLTM is designated as k_M.

Note. – Figure A2-2 is an example of a flyover noise time history where the maximum value is clearly indicated.

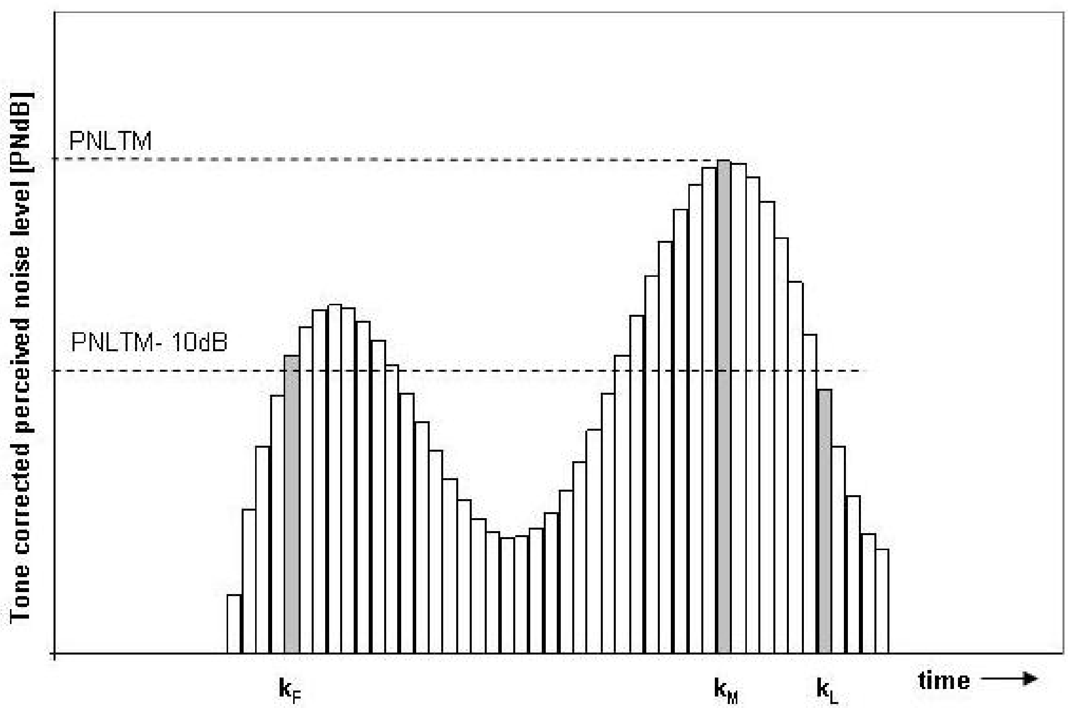


Figure A2-2. Example of a flyover noise time history

4.4.2 The tone at PNLTM may be suppressed due to one-third octave bandsharing of that tone. To identify whether this is the case the average of the tone correction factors of the PNLTM spectrum and the two preceding and two succeeding spectra is calculated. If the value of the tone correction factor $C(k_M)$ for the spectrum associated with PNLTM is less than the average value of $C(k)$ for the five consecutive spectra (k_M-2) through (k_M+2), then the average value C_{avg} shall be used to compute a bandsharing adjustment, Δ_B, and a value of PNLTM adjusted for bandsharing.

$$C_{avg} = [C(k_M-2) + C(k_M-1) + C(k_M) + C(k_M+1) + C(k_M+2)] / 5$$

If $C_{avg} > C(k_M)$ then $\Delta_B = C_{avg} - C(k_M)$, and

$\mathrm{PNLTM} = \mathrm{PNLT}(k_M) + \Delta_B$

4.4.3 The value of PNLTM adjusted for bandsharing must be used for the calculation of EPNL.

4.5 Noise duration

4.5.1 The limits of the noise duration are bounded by the first and last 10 dB-down points. These are determined by examination of the PNLT(*k*) time history with respect to PNLTM.

a) The earliest value of PNLT(*k*) which is greater than PNLTM-10 dB is identified. This value and the value of PNLT for the preceding point are compared. Whichever of these two points is associated with the value closest to PNLTM-10 dB is identified as the first 10 dB-down point. The associated increment is designated as k_F.

b) The last value of PNLT(*k*) which is greater than PNLTM-10 dB is identified. This value and the value of PNLT for the following point are compared. Whichever of these two points is associated with the value closest to PNLTM-10 dB is identified as the last 10 dB-down point. The associated increment is designated as k_L.

Note.— Figure A2-2 illustrates the selection of the first and last 10 dB-down points, k_F *and* k_L.

4.5.2 The noise duration in seconds shall be equal to the number of PNLT(*k*) values from k_F to k_L inclusive, times 0.5.

4.5.3 The value of PNLTM used for determination of the 10 dB-down points must include the adjustment for the presence of bandsharing, ΔB, by the method of Section 4.4.2.

4.6 Effective perceived noise level

4.6.1 If the instantaneous tone corrected perceived noise level is expressed in terms of a continuous function with time, PNLT(*t*), then the effective perceived noise level, EPNL, would be defined as the level, in EPNdB, of the time integral of PNLT(*t*) over the noise event duration, normalized to a reference duration, T_0, of 10 seconds. The noise event duration is bounded by t_1, the time when PNLT(*t*) is first equal to PNLTM-10, and t_2, the time when PNLT(*t*) is last equal to PNLTM-10.

$$\mathrm{EPNL} = 10\log\frac{1}{T_0}\int_{t1}^{t2}10^{0.1\,\mathrm{PNLT}\,(t)}dt$$

4.6.2 In practice PNLT is not expressed as a continuous function with time since it is computed from discrete values of PNLT(*k*) every half second. In this case the basic working definition for EPNL is obtained by replacing the integral in Section 4.6.1 with the following summation expression:

$$\mathrm{EPNL} = 10\log\frac{1}{T_0}\sum_{k_F}^{k_L}10^{0.1\mathrm{PNLT}\,(k)}\Delta t$$

For T_0 = 10 and Δt = 0.5 this expression can be simplified as follows:

$$\text{EPNL} = 10\log\sum_{k_F}^{k_L} 10^{0.1\text{PNLT }(k)} - 13$$

Note.— 13 dB is a constant relating the one-half second values of PNLT(k) to the 10 second reference duration T_0: 10 log (0.5 / 10) = -13

4.6.3 The value of PNLTM used for determination of EPNL must include the adjustment for the presence of bandsharing, Δ_B, by the method of Section 4.4.2.

. . .

See Work Items N. 15 and N. 21

5. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY

. . .

5.4 Validity of results

. . .

5.4.2 The minimum sample size acceptable for each of the three certification measuring points for aeroplanes and for each set of three microphones for helicopters is six. The samples shall be large enough to establish statistically for each of the three average noise certification levels a 90 per cent confidence limit not exceeding ±1.5 EPNdB. No test result shall be omitted from the averaging process unless otherwise specified by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in ~~Appendix 1~~ the section of Doc 9501, Volume I concerning the calculation of confidence intervals.

Replace Sections 8 and 9 with the new Section 8 as follows:

8. ADJUSTMENT OF AIRCRAFT FLIGHT TEST RESULTS

8.1 Flight Profiles and Noise Geometry

Flight profiles for both test and reference conditions are described by their geometry relative to the ground, the associated aircraft ground speed, and, in the case of aeroplanes, the associated engine control parameter(s) used for determining the acoustic emission of the aeroplane. Idealised aircraft flight profiles are described in 8.1.1 for aeroplanes and 8.1.2 for helicopters.

Note.— The "noise flight path" referred to in 8.1.1 and 8.1.2 is defined in accordance with the requirements of 2.3.2.

8.1.1 Aeroplane flight profiles

8.1.1.1 Reference lateral full-power profile characteristics

Figure A2-4 illustrates the profile characteristics for the aeroplane take-off procedure for noise measurements made at the lateral full-power noise measurement points:

a) The aeroplane begins the take-off roll at point A and lifts off at point B at full take-off power. The climb angle increases between points B and C. From point C the climb angle is constant up to point F, the end of the noise flight path.

b) Positions K_{2L} and K_{2R} are the left and right lateral noise measurement points for jet aeroplanes, located on a line parallel to and at the specified distance abeam the runway centre line, where the noise level during take-off is greatest. Position K_4 is the “lateral” full-power noise measurement point for propeller-driven aeroplanes located on the extended centre line of the runway vertically below the point on the climb-out flight path where the aeroplane is at the specified height.

8.1.1.2 Reference flyover profile characteristics

Figure A2-5 illustrates the profile characteristics for the aeroplane take-off procedure for noise measurements made at the flyover noise measurement point:

a) The aeroplane begins the take-off roll at point A and lifts off at point B at full take-off power. The climb angle increases between points B and C. From point C the climb angle is constant up to point D where thrust (or power) reduction is initiated. At point E the thrust (or power) and climb angle are once more stabilized and the aeroplane continues to climb at a constant angle up to point F, the end of the noise flight path.

Note.— The flyover profile may be flown without thrust (power) reduction in which case point C will extend through point D at a constant climb angle.

b) Position K_1 is the flyover noise measurement point and AK_1 is the specified distance from start of roll to the flyover noise measuring point.

8.1.1.3 Reference approach profile characteristics

Figure A2-6 illustrates the profile characteristics for the aeroplane approach procedure for noise measurements made at the approach noise measurement point:

a) The aeroplane is initially stabilized on the specified glideslope at point G and continues through point H and point I, touching down on the runway at point J.

b) Position K_3 is the approach noise measurement point and K_3O is the specified distance from the approach noise measurement point to the runway threshold.

Note.— The aeroplane reference point during approach measurements shall be the ILS antenna.

8.1.2 Helicopter flight profiles

8.1.2.1 Reference take-off profile characteristics

Figure A2-7 illustrates the profile characteristics for the helicopter take-off procedure for noise measurements made at the take-off noise measurement point:

a) The helicopter is initially stabilized in level flight at point A at the best rate of climb speed V_y. The helicopter continues to point B where take-off power is applied and a steady climb is initiated. A steady climb is maintained through point X and beyond to point F, the end of the noise flight path.

b) Position K_1 is the take-off noise measurement point and NK_1 is the specified distance from the initiation of the steady climb to the take-off reference noise measurement point. Positions K_1' and K_1'' are associated noise measurement points located on a line $K_1' K_1''$ through K_1 at right angles to the take-off flight track TM and at the specified distance either side of K_1.

Note.— In practice the point at which take-off power is applied will be some distance before point B.

8.1.2.2 Reference overflight profile characteristics

Figure A2-8 illustrates the profile characteristics for the helicopter overflight procedure for noise measurements made at the overflight noise measurement points:

a) The helicopter is stabilized in level flight at point D and flies through point W, overhead the overflight noise measurement point K_2, to point E, the end of the noise flight path.

b) Position K_2 is the overflight noise measurement point and K_2W is the specified height of the helicopter overhead the overflight noise measurement point. Positions K_2' and K_2'' are associated noise measurement points located on a line $K_2' K_2''$ through K_2 at right angles to the overflight flight track RS and at the specified distance either side of K_2.

8.1.2.3 Reference approach profile characteristics

Figure A2-9 illustrates the profile characteristics for the helicopter approach procedure for noise measurements made at the approach noise measurement points:

a) The helicopter is initially stabilized on the specified glideslope at point G and continues through point H and point I, touching down at point J.

b) Position K_3 is the approach noise measurement point and K_3H is the specified height of the helicopter overhead the approach noise measurement point. Positions K_3' and K_3'' are associated noise measurement points located on a line $K_3' K_3''$ at right angles to the approach flight track PU and at the specified distance either side of K_3.

8.1.3 Adjustment of measured noise levels from measured to reference profile in the calculation of EPNL

Note.— The "useful portion of the measured flight path" referred to in this section is defined in accordance with the requirements of 2.3.2.

8.1.3.1 For the case of a microphone located beneath the flight path, the portions of the test flight path and the reference flight path which are significant for the adjustment of the measured noise levels from the measured profile to the reference profile in the EPNL calculation are illustrated in Figure A2-10, where:

a) XY represents the useful portion of the measured flight path (Figure A2-10 a)), and X_rY_r that of the corresponding reference flight path (Figure A2-10 b)).

b) K is the actual noise measurement point and K_r the reference noise measurement point. Q represents the aircraft position on the measured flight path at which the noise was emitted and observed as PNLTM at point K. The angle between QK and the direction of flight along the measured flight path is θ, the acoustic emission angle. Q_r is the corresponding position on the reference flight path where the angle between Q_rK_r is also θ. QK and Q_rK_r are respectively the measured and reference noise propagation paths.

Note.— This situation will apply in the case of aeroplanes for the flyover, approach, and for propeller-driven aeroplanes only, the lateral full-power noise measurements, and in the case of helicopters for the take-off, overflight, and approach noise measurements for the centre microphone only.

8.1.3.2 For the case of a microphone laterally displaced to the side of the flight path, the portions of the test flight path and the reference flight path which are significant for the adjustment of the measured noise levels from the measured profile to the reference profile in the EPNL calculation are illustrated in Figure A2-11, where:

a) XY represents the useful portion of the measured flight path (Figure A2-11 a)), and X_rY_r that of the corresponding reference flight path (Figure A2-11 b)).

b) K is the actual noise measurement point and K_r the reference noise measurement point. Q represents the aircraft position on the measured flight path at which the noise was emitted and observed as PNLTM at point K. The angle between QK and the direction of flight along the measured flight path is θ, the acoustic emission angle. The angle between QK and the ground is ψ, the elevation angle. Q_r is the corresponding position on the reference flight path where the angle between Q_rK_r and the direction of flight along the reference flight path is also θ, and the angle between Q_rK_r and the ground is ψ_r, where in the case of aeroplanes, the difference between ψ and ψ_r is minimised.

Note.— This situation will apply in the case of jet aeroplanes for the lateral full-power noise measurements, and in the case of helicopters for the take-off, overflight, and approach noise measurements for the two laterally displaced microphones only.

8.1.3.3 n both situations the acoustic emission angle θ shall be established using three dimensional geometry.

8.1.3.4 In the case of lateral full power noise measurements of jet aeroplanes the extent to which differences between ψ and ψ_r can be minimised is dependent on the geometrical restrictions imposed by the need to maintain the reference microphone on a line parallel to the extended runway centre line.

Note.— In the case of helicopter measurements there is no requirement to minimise the difference between ψ and ψ_r. However these angles shall be determined and reported.

8.2 Selection of Adjustment Method

8.2.1 Adjustments to the measured noise values shall be made for the following:

a) aircraft flight path and velocity relative to the microphone;

b) sound attenuation in air; and

c) source noise

8.2.2 For helicopters, the simplified method described in 8.3 shall be used.

Note.— The integrated method may be approved by the certificating authority as being equivalent to the simplified method.

8.2.3 For aeroplanes, either the simplified method, described in 8.3, or the integrated method described in 8.4 shall be used for the lateral, flyover or approach conditions. The integrated method shall be used when:

a) for flyover, the absolute value of the difference between the value of $EPNL_r$, when calculated according to the simplified method described in 8.3.1, and the measured value of EPNL calculated according to the procedure described in 4.1.3 is greater than 8 EPNdB;

b) for approach, the absolute value of the difference between the value of $EPNL_r$, when calculated according to the simplified method described in 8.3.1, and the measured value of EPNL calculated according to the procedure described in 4.1.3 is greater than 4 EPNdB; or

c) for flyover or approach, the value of $EPNL_r$, when calculated according to the simplified method described in 8.3.1, is greater than the maximum noise levels prescribed in 3.4 of Part II, Chapter 3, less 1 EPNdB.

Note.— Part II, Chapter 3, 3.7.6 specifies limitations regarding the validity of test data based upon both the extent to which $EPNL_r$ differs from EPNL, and also the proximity of the final $EPNL_r$ values to the maximum permitted noise levels, regardless of the method used for adjustment.

8.3 Simplified method of adjustment

8.3.1 General

8.3.1.1 The simplified adjustment method consists of the determination and application of adjustments to the EPNL calculated from the measured data for the differences between measured and reference conditions at the moment of PNLTM. The adjustment terms are:

a) Δ_1 – adjustment for differences in the PNLTM spectrum under test and reference conditions – see 8.3.2;

b) Δ_{Peak} – adjustment for when the PNLT for a secondary peak, identified in the calculation of EPNL from measured data and adjusted to reference conditions, is greater than the PNLT for the adjusted PNLTM spectrum – see 8.3.3;

c) Δ_2 – adjustment for the difference in noise duration, taking into account the differences between test and reference aircraft speed and position relative to the microphone – see 8.3.4; and

d) Δ_3 – adjustment for differences in source noise generating mechanisms – see 8.3.5.

8.3.1.2 The emission coordinates (time, X,Y, and Z) of the reference data point associated with PNLTMr shall be determined such that the acoustic emission angle θ on the reference flight path, relative to the reference microphone, is the same value as the acoustic emission angle of the as-measured data point associated with PNLTM.

8.3.1.3 The adjustment terms described in 8.3.2 to 8.3.5 are applied to the EPNL calculated from measured data to obtain the simplified reference condition effective perceived noise level, $EPNL_r$ as described in 8.3.6.

8.3.1.4 Any asymmetry in the lateral noise shall be accounted for in the determination of EPNL as described in 8.3.7.

8.3.2 Adjustments to spectrum at PNLTM

8.3.2.1 The one-third octave band levels SPL(i) used to construct PNL(k_M) (the PNL at the moment of PNLTM observed at measurement point K) shall be adjusted to reference levels $SPL_r(i)$ as follows:

$$SPL_r(i) = SPL(i) + 0.01\,[\alpha(i) - \alpha\,(i)_0]\,QK$$
$$+\,0.01\,\alpha(i)_0\,(QK - Q_rK_r)$$
$$+\,20\log(QK/Q_rK_r)$$

In this expression,

- the term $0.01\,[\alpha(i) - \alpha(i)_0]\,QK$ accounts for the effect of the change in sound attenuation due to atmospheric absorption, and $\alpha(i)$ and $\alpha(i)_0$ are the coefficients for the test and reference atmospheric conditions respectively, obtained from Section 7;

- the term $0.01\,\alpha(i)_0\,(QK - Q_rK_r)$ accounts for the effect of the change in the noise path length on the sound attenuation due to atmospheric absorption;

- the term $20\log(QK/Q_rK_r)$ accounts for the effect of the change in the noise path length due to spherical spreading (also known as the "inverse square" law);

- QK and Q_rK_r are measured in metres and $\alpha(i)$ and $\alpha(i)_0$ are obtained in the form of dB/100 m.

Note.— Refer to Figure A2-10 and A2-11 for identification of positions and distances referred to in this paragraph.

8.3.2.2 The adjusted values of $SPL_r(i)$ obtained in 8.3.2.1 shall be used to calculate a reference condition PNLT value, $PNLT_r(k_M)$, as described in 4.2 and 4.3 of this appendix. The value of the bandsharing adjustment, Δ_B, calculated for the test-day PNLTM by the method of 4.4.2, shall be added to this $PNLT_r(k_M)$ value to obtain the reference condition $PNLTM_r$:

$$PNLTM_r = PNLT_r(k_M) + \Delta_B$$

An adjustment term, Δ_1, is then calculated as follows:

$$\Delta_1 = PNLTM_r - PNLTM$$

8.3.2.3 Δ_1 shall be added algebraically to the EPNL calculated from measured data as described in 8.3.6.

8.3.3 Adjustment for secondary peaks

8.3.3.1 During a test flight any values of PNLT that are within 2 dB of PNLTM are defined as "secondary peaks". The one-third octave band levels for each "secondary peak" shall be adjusted to reference conditions according to the procedure defined in 8.3.2.1. Adjusted values of PNLTr shall be calculated for each "secondary peak" as described in 4.2 and 4.3 of this appendix. If any adjusted peak value of $PNLT_r$ exceeds the value of $PNLTM_r$, a Δ_{Peak} adjustment shall be applied.

8.3.3.2 Δ_{Peak}, shall be calculated as follows:

$$\Delta_{Peak} = PNLT_r(MaxPeak) - PNLTM_r$$

where $PNLT_r(MaxPeak)$ is the reference condition PNLT value of the largest of the secondary peaks; and $PNLTM_r$ is the reference condition PNLT value at the moment of PNLTM.

8.3.3.3 Δ_{Peak} shall be added algebraically to the EPNL calculated from measured data as described in 8.3.6.

8.3.4 Adjustment for effects on noise duration

8.3.4.1 Whenever the measured flight paths and/or the ground velocities of the test conditions differ from the reference flight paths and/or the reference ground velocities, adjustments to noise duration shall be determined as follows.

8.3.4.2 Referring to the flight paths shown in Figures A2-10 and A2-11, the adjustment term Δ_2 shall be calculated from the measured data as follows:

$$\Delta_2 = -7.5 \log (QK/Q_rK_r) + 10 \log (V_G/V_{Gr})$$

where:

- V_G is the test ground speed (horizontal component of the test airspeed); and
- V_{Gr} is the reference ground speed (horizontal component of the reference airspeed).

Note.— The factors, –7.5 and 10, have been determined empirically from a representative sample *population of certificated aeroplanes and helicopters. The factors account for the effects of changes in noise duration on EPNL due to distance and speed respectively.*

8.3.4.3 Δ_2 shall be added algebraically to the EPNL calculated from measured data as described in 8.3.6.

8.3.5 Source noise adjustments

8.3.5.1 The source noise adjustment shall be applied to take account of differences in test and reference source noise generating mechanisms. For this purpose the effect on aircraft propulsion source noise of differences between the acoustically significant propulsion operating parameters actually realized in the certification flight tests and those calculated or specified for the reference conditions of Chapter 3, 3.6.1.5 is determined. Such operating parameters may include for jet aeroplanes, the engine control parameter μ (typically normalized low pressure fan speed, normalized engine thrust or engine pressure ratio), for propeller driven aeroplanes both shaft horse-power and propeller helical tip Mach number and for helicopters, during overflight only, advancing rotor blade tip Mach number. The adjustment shall be determined from manufacturer's data approved by the certificating authority.

8.3.5.2 For aeroplanes, the adjustment term Δ_3 shall normally be determined from sensitivity curve(s) of EPNL versus the propulsion operating parameter(s) referred to in 8.3.5.1. It is obtained by subtracting the EPNL value corresponding to the measured value of the correlating parameter from the EPNL value corresponding to the reference value of the correlating parameter. The adjustment term Δ_3 shall be added algebraically to the EPNL value calculated from the measured data — see 8.3.6.

Note.— Representative data for jet aeroplanes are illustrated in Figure A2-12 which shows a curve of EPNL versus the engine control parameter μ. The EPNL data is adjusted to all other relevant reference conditions (aeroplane mass, speed, height, and air temperature) and, at each value of μ, for the difference in noise between the installed engine and the flight manual standard of engine.

8.3.5.3 For jet aeroplanes, noise data acquired from measurements conducted at test site locations at or above 366 m (1200 ft) above mean sea level (MSL) shall in addition be adjusted for the effects on jet source noise.

Note.— A procedure for determining and applying the adjustment for the effects on jet source noise is given in the section of Doc 9501, Volume I, concerning noise data adjustments for test at high altitude sites.

8.3.5.4 For jet aeroplanes, when the test and reference true airspeeds differ by more than 28 km/h (15 kt), the effect of the difference in airspeed on engine component noise sources and the consequential effect on the certification noise levels shall be taken into account. Test data and/or analysis procedures used to quantify this effect shall be approved by the certificating authority.

8.3.5.5 For helicopter overflight, if any combination of the following three factors results in the measured value of an agreed noise correlating parameter deviating from the reference value of this parameter, then source noise adjustments shall be determined from manufacturer's data approved by the certificating authority.

a) airspeed deviations from reference;

b) rotor speed deviations from reference;

c) temperature deviations from reference;

This adjustment should normally be made using a sensitivity curve of PNLTMr versus advancing blade tip Mach number. The adjustment may be made using an alternative parameter, or parameters, approved by the certificating authority.

Note 1.— If it is not possible during noise measurement tests to attain the reference value of advancing blade tip Mach number or the agreed reference noise correlating parameter, then an extrapolation of the sensitivity curve is permitted provided the data cover an adequate range of values, agreed by the certificating authority, of the noise correlating parameter. The advancing blade tip Mach number, or agreed noise correlating parameter, shall be computed from as measured data. Separate curves of $PNLTM_r$ *versus advancing blade tip Mach number, or another agreed noise correlating parameter, shall be derived for each of the three certification microphone locations, centre line, left sideline and right sideline, defined relative to the direction of flight of each test run.*

Note 2.— When using advancing blade tip Mach number it should be computed using true airspeed, on-board outside air temperature (OAT), and rotor speed.

8.3.5.6 For helicopters, the adjustment term Δ_3, obtained according to 8.3.5.5 shall be added algebraically to the EPNL value calculated from the measured data as described in 8.3.6.

8.3.6 Application of adjustment terms for simplified method

Determine EPNL for reference conditions, $EPNL_r$, using the simplified method, by adding the adjustment terms identified in 8.3.2 through 8.3.5 to the EPNL calculated for measurement conditions as follows:

$$EPNL_r = EPNL + \Delta_1 + \Delta_{Peak} + \Delta_2 + \Delta_3$$

8.3.7 Lateral noise asymmetry

For the determination of the lateral noise level for jet aeroplanes, asymmetry (see Chapter 3, 3.3.2.2) shall be accounted for as follows:

- if a symmetrical measurement point is opposite the point where the highest noise level is obtained, the certification noise level shall be the (arithmetical) mean of the noise levels measured at these two points (see Figure A2-13 a));

- if not, it shall be assumed that the variation of noise with the height of the aeroplane is the same on both sides (i.e. there is a constant difference of noise versus height on the two sides (see Figure A2-13 b)). The certification noise level shall then be the maximum value of the mean between these lines.

8.4 Integrated method of adjustment

8.4.1 General

8.4.1.1 The integrated method consists of recomputing under reference conditions points in the PNLT time history corresponding to measured points obtained during the tests, and then computing EPNL directly for the new time history.

8.4.1.2 The emission coordinates (time, X,Y, and Z) of the reference data point associated with each $PNLT_r(k)$ shall be determined such that the acoustic emission angle θ on the reference flight path, relative to the reference microphone, is the same value as the acoustic emission angle of the as-measured data point associated with PNLT(k).

Note.— As a consequence, and unless the test and reference conditions are identical, the reception time intervals between the reference data points will typically neither be equally-spaced nor equal to one-half second.

8.4.1.3 The steps in the integrated procedure are as follows:

a) The spectrum associated with each test-day data point, PNLT(k), is adjusted for spherical spreading and attenuation due to atmospheric absorption, to reference conditions – see 8.4.2.1;

b) A reference tone-corrected perceived noise level, $PNLT_r(k)$, is calculated for each one third octave band spectrum – see 8.4.2.2;

c) The maximum value, $PNLTM_r$ and first and last 10 dB-down points are determined from the $PNLT_r$ series – see 8.4.2.3 and 8.4.3.1;

d) The effective duration, $\delta t_r(k)$, is calculated for each $PNLT_r(k)$ point, and the reference noise duration is then determined – see 8.4.3.2, 8.4.3.3 and 8.4.3.4;

e) The integrated reference condition effective perceived noise level, $EPNL_r$, is determined by the logarithmic summation of $PNLT_r(k)$ levels within the noise duration normalized to a duration of 10 seconds – see 8.4.4; and

f) A source noise adjustment is determined and applied – See 8.4.5.

8.4.2 PNLT computations

8.4.2.1 The measured values of SPL(i,k) shall be adjusted to the reference values $SPL_r(i,k)$ for the differences between measured and reference sound propagation path lengths and between measured and reference atmospheric conditions, by the methods of 8.3.2.1. Corresponding values of $PNL_r(k)$ shall be computed as described in 4.2.

8.4.2.2 For each value of $PNL_r(k)$, a tone correction factor C shall be determined by analyzing each reference value $SPL_r(i,k)$ by the methods of 4.3, and added to $PNL_r(k)$ to obtain $PNLT_r(k)$.

8.4.2.3 The maximum reference condition tone corrected perceived noise level, $PNLTM_r$, shall be identified, and a new reference condition bandsharing adjustment, Δ_{Br}, shall be determined and applied as described in 4.4.2.

Note.— Due to differences between test and reference conditions, it is possible that the maximum $PNLT_r$ value will not occur at the data point associated with PNLTM. The determination of $PNLTM_r$ is independent of PNLTM.

8.4.3 Noise Duration

8.4.3.1 The limits of the noise duration shall be defined as the 10 dB-down points obtained from the series of reference condition $\text{PNLT}_r(k)$ values. Identification of the 10 dB-down points shall be performed in accordance with 4.5.1. In the case of the integrated method the first and last 10 dB-down points shall be designated as $k_{\text{F}r}$ and $k_{\text{L}r}$.

8.4.3.2 The noise duration for the integrated reference condition shall be equal to the sum of the effective durations, $\delta t_r(k)$, associated with each of the $\text{PNLT}_r(k)$ data points within the 10 dB-down period, inclusive.

8.4.3.3 The effective duration, $\delta t_r(k)$, shall be determined for each $\text{PNLT}_r(k)$ reference condition data point as follows:

$$\delta t_r(k) = [\, (t_r(k) - t_r(k-1)) + (t_r(k+1) - t_r(k)) \,] / 2$$

where:

- $t_r(k)$ is the time associated with $\text{PNLT}_r(k)$;
- $t_r(k-1)$ is the time associated with $\text{PNLT}_r(k-1)$, the data point preceding $\text{PNLT}_r(k)$; and
- $t_r(k+1)$ is the time associated with $\text{PNLT}_r(k+1)$, the data point following $\text{PNLT}_r(k)$.

Note 1.— Due to differences in flight path geometry, airspeed, and sound speed between test and reference conditions, the times, $t_r(k)$, associated with the $PNLT_r(k)$ points projected to the reference flight path are likely to occur at varying, non-uniform time intervals.

Note 2.— Relative values of time $t_r(k)$ for the reference data points can be determined by using the distance between such points on the reference flight path, and the reference aircraft airspeed V_r.

Note 3.— Doc 9501, Volume I, provides additional guidance for one method for performing the integrated procedure, including the determination of effective durations, $\delta t_r(k)$, for the individual data points of the reference time history.

8.4.4 Calculation of integrated reference condition EPNL

8.4.4.1 The equation for calculating reference condition EPNL using the integrated method, EPNL_r, is similar to the equation for test-day EPNL given in 4.6. However, the numerical constant related to one-half second intervals is eliminated, and a multiplier is introduced within the logarithm to account for the effective duration of each $\text{PNLT}_r(k)$ value, $\delta t_r(k)$:

$$\text{EPNL} = 10 \log \frac{1}{T_0} \sum_{k_{\text{F}r}}^{k_{Lr}} 10^{0.1\text{PNLT}_{\text{r}}(k)} \delta \text{t}_r(k)$$

where:

- the reference time, T_0, is 10 seconds;

- k_{Fr} and k_{Lr} are the first and last 10 dB-down points as defined in 8.4.3.1; and

- $\delta t_r(k)$ is the effective duration as defined in 8.4.3.3 of each reference condition $PNLT_r(k)$ value.

8.4.5 Source noise adjustment

8.4.5.1 Finally, a source noise adjustment shall be determined by the methods of 8.3.5, and added to the $EPNL_r$ determined in 8.4.4.1.

8.4.5.2 For jet aeroplanes, noise data acquired from measurements conducted at test site locations at or above 366 m (1200 ft) above mean sea level (MSL) shall in addition be adjusted for the effects on jet source noise.

Note.— A procedure for determining the adjustment for the effects on jet source noise is given in the section of Doc 9501; Volume I, concerning noise data adjustments for test at high altitude sites.

Insert the following figures into the text of Appendix 2 where appropriate:

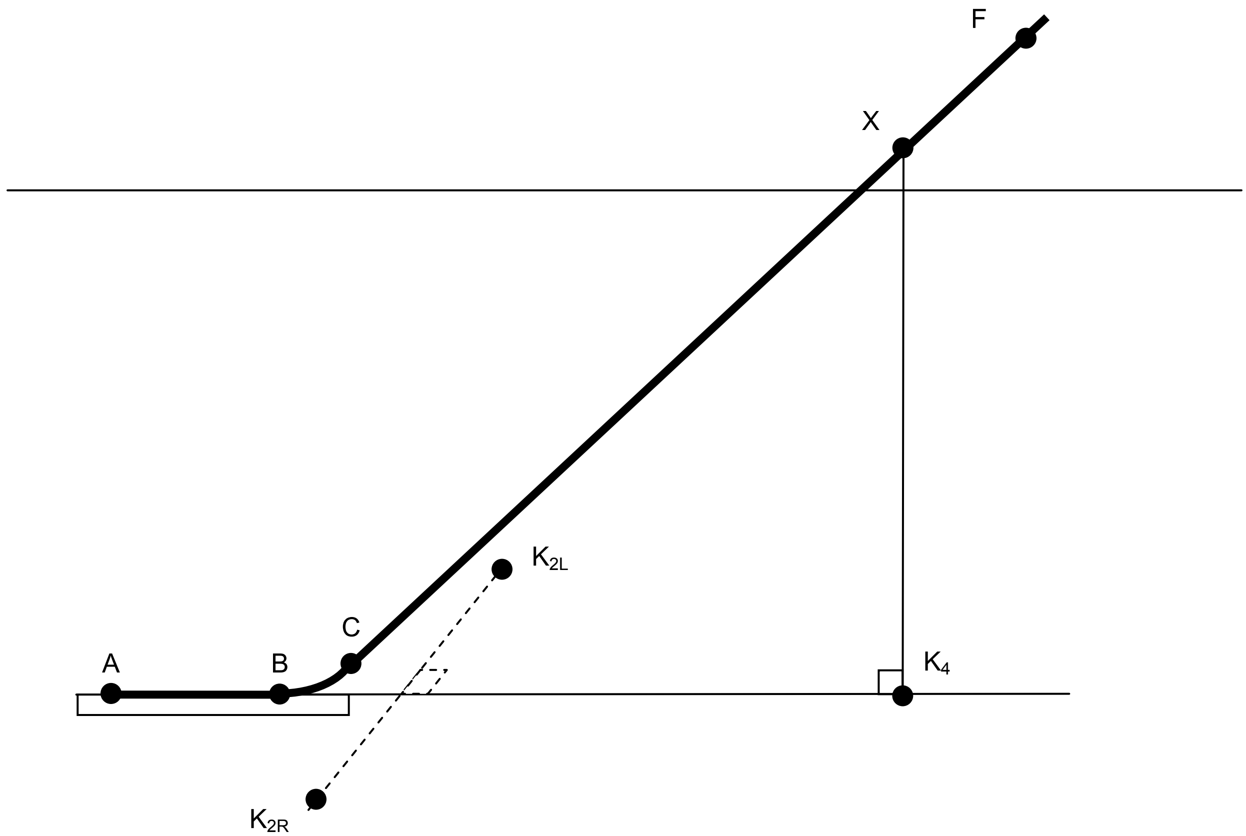


Figure A2-4. Reference aeroplane lateral full-power profile characteristics

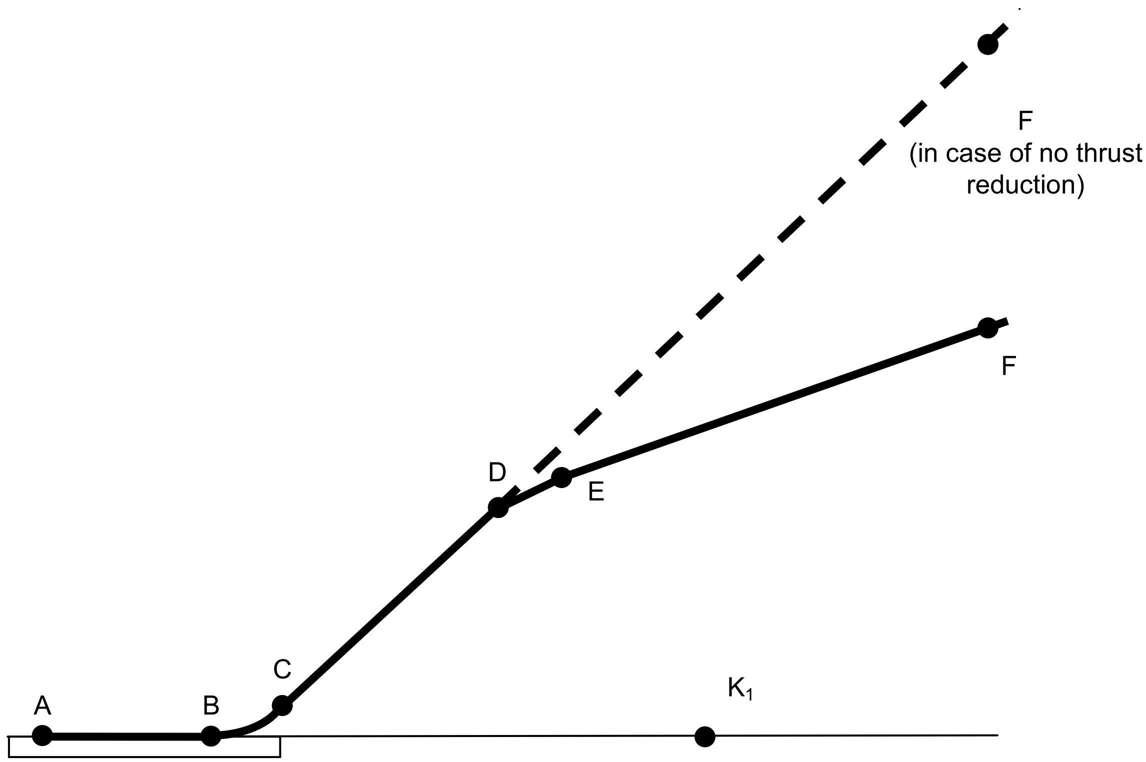


Figure A2-5. Reference aeroplane flyover profile characteristics

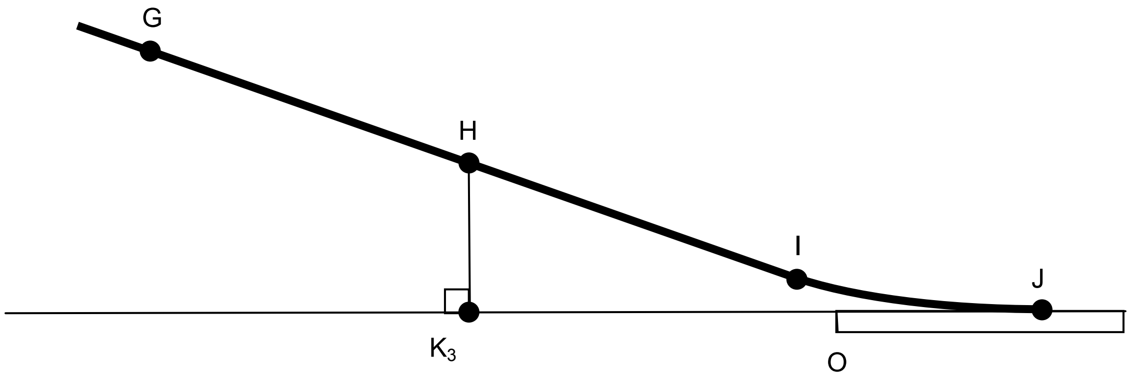


Figure A2-6. Reference aeroplane approach profile characteristics

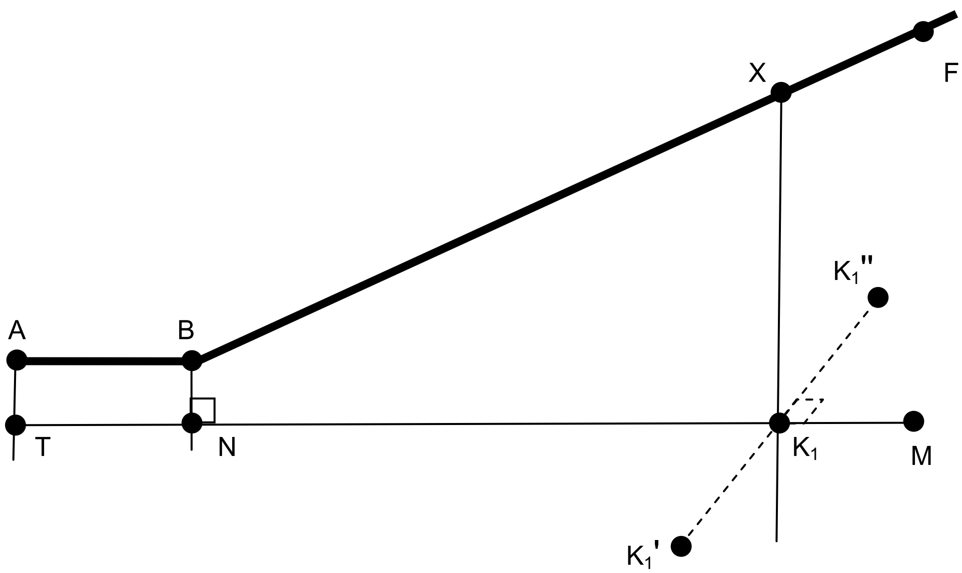


Figure A2-7. Reference helicopter take-off profile characteristics

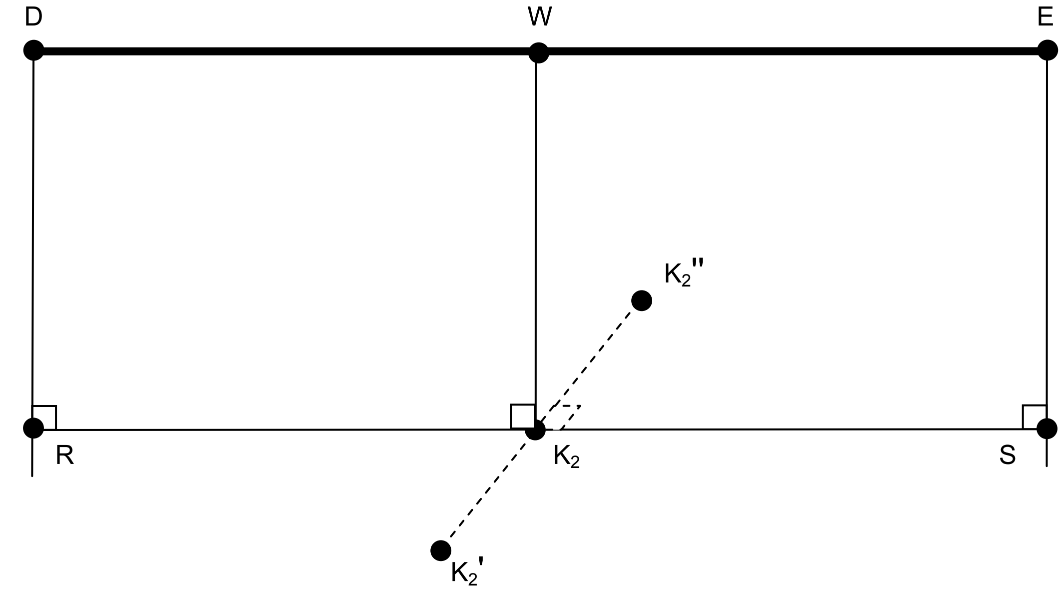


Figure A2-8. Reference helicopter overflight profile characteristics

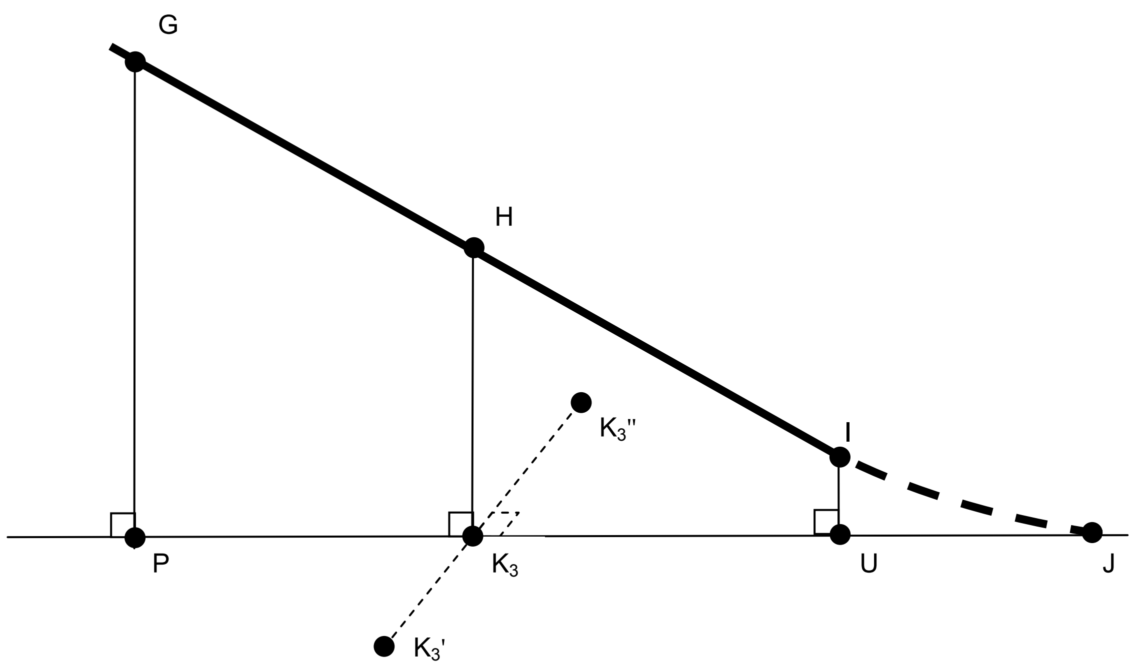


Figure A2-9. Reference helicopter approach profile characteristics

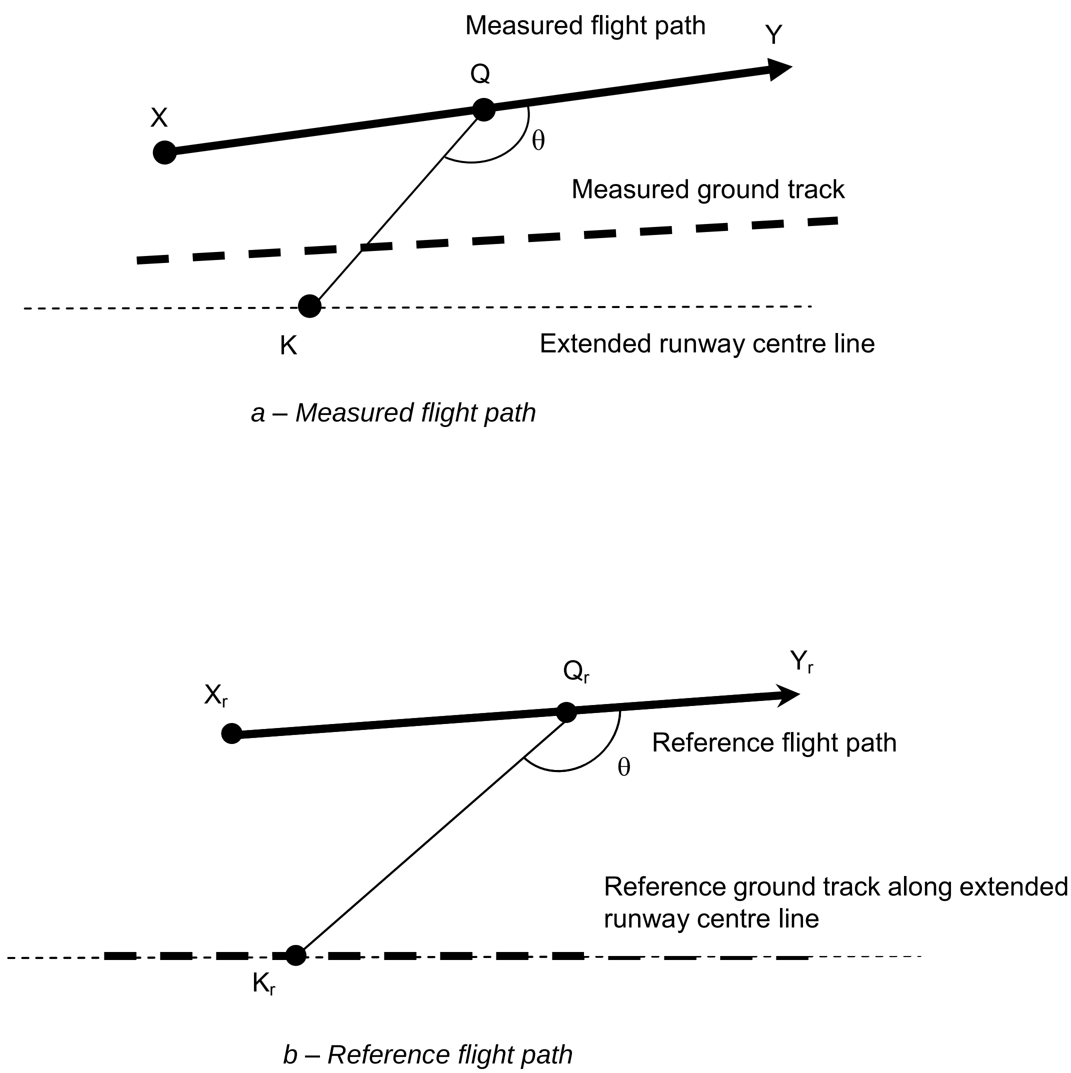
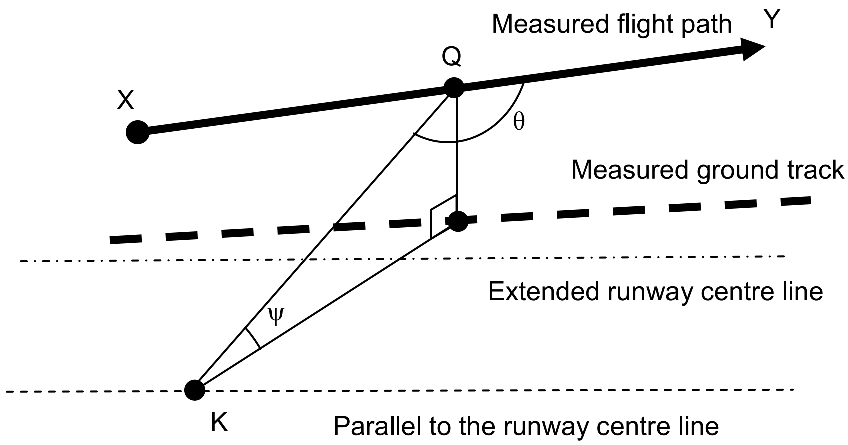
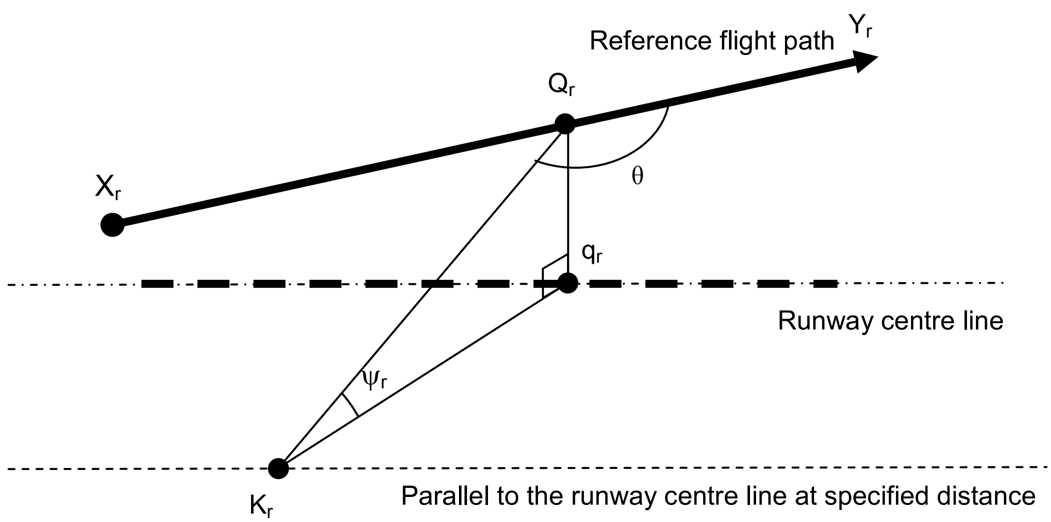


Figure A2-10. Profile characteristics influencing noise level for microphone located beneath the flight path.



a – Measured flight path



b – Reference flight path

Figure A2-11. Profile characteristics influencing noise level for laterally displaced microphone.

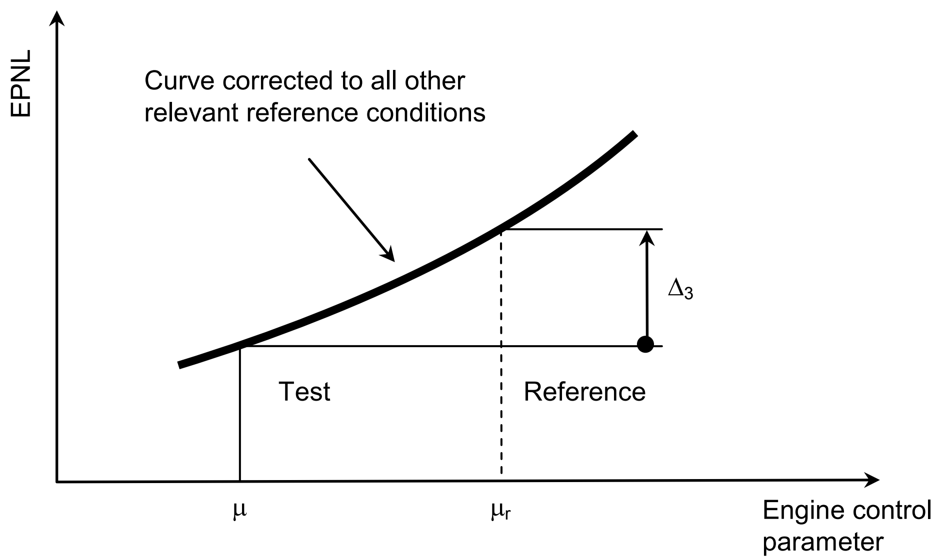


Figure A2-12. Source noise adjustment

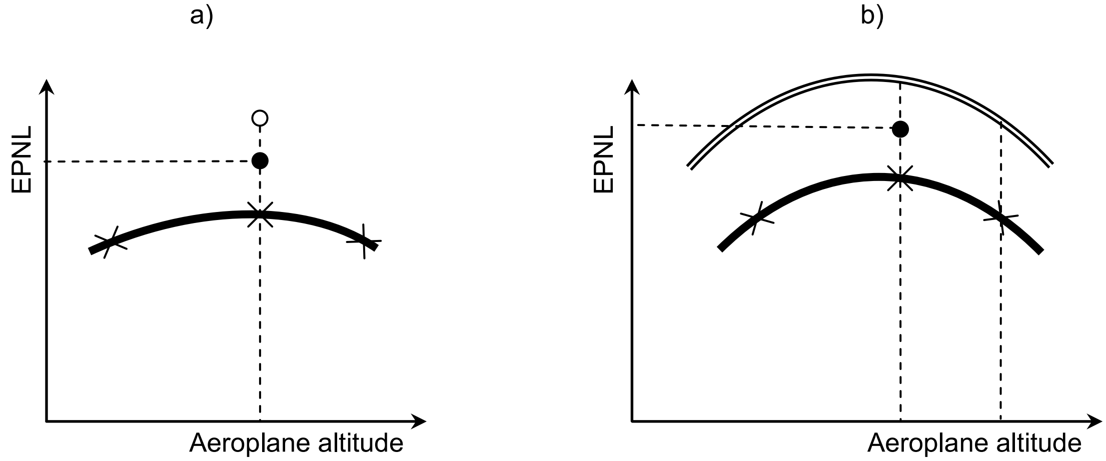


Figure A2-13. Lateral asymmetry adjustments

See Work Items N. 15, N. 16 and N. 21

APPENDIX 3. ~~NOISE~~ EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — ~~APPLICATION FOR TYPE CERTIFICATE SUBMITTED BEFORE 17 NOVEMBER 1988~~ Application for Type Certificate submitted before 17 November 1988

. . .

4. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND CORRECTION OF MEASURED DATA

. . .

4.2 Data correction

4.2.1 Correction of noise at source

. . .

4.2.1.2 At a propeller helical tip Mach number at or below 0.70 no correction is required if the test helical tip Mach number is within 0.014 of the reference helical tip Mach number. At a propeller helical tip Mach number above 0.70 and at or below 0.80 no correction is required if the test helical tip Mach number is within 0.007 of the reference helical tip Mach number. Above a helical tip Mach number of 0.80 no correction is required if the helical tip Mach number is within 0.005 of the reference helical tip Mach number. If the test power at any helical tip Mach number is within 10 per cent of the reference power, no correction for source noise variation with power is required. No corrections are to be made for power changes for fixed pitch propeller-driven aeroplanes. If test propeller helical tip Mach number and power variations from reference conditions are outside these constraints, corrections based on data developed using the actual test aeroplane or a similar configured aeroplane with the same engine and propeller operating as the aeroplane being certificated shall be used as described in ~~Section 4.1 of the *Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft* (~~Doc 9501~~)~~, Volume I concerning source noise adjustments for aeroplanes evaluated under this appendix.

. . .

4.3 Validity of results

. . .

4.3.2 The samples shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test result shall be omitted from the averaging process, unless otherwise specified by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in ~~Appendix 1 of Doc 9501~~ the Section of Doc 9501 concerning calculation of confidence intervals.

See Work Items N. 15 and N. 21

APPENDIX 4. EVALUATION METHOD FOR NOISE CERTIFICATION OF HELICOPTERS NOT EXCEEDING 3 175 kg MAXIMUM CERTIFICATED TAKE-OFF MASS

. . .

3. NOISE UNIT DEFINITION

. . .

3.3 The above integral can be approximated from periodically sampled measurement as:

$$L_{AE} = 10 \log \frac{1}{T_0} \sum_{t=1}^{n(t2-t1)} 10^{(0.1L_A(t))}$$

$$L_{AE} = 10 \log \frac{1}{T_0} \sum_{k_F}^{k_L} 10^{0.1L_A(k)} \Delta t$$

where $L_A(t)$ $L_A(k)$ is the time varying A-frequency-weighted S-time-weighted sound level and n is the number of samples per second measured at the k^th instant of time, k_F and k_L are the first and last increment of k, and Δt is the time increment between samples.

. . .

5. ADJUSTMENT TO TEST RESULTS

. . .

5.2 Corrections and adjustments

. . .

5.2.3 The adjustment for the difference between reference airspeed and adjusted reference airspeed is calculated from:

$$\Delta_2 = 10 \log_{10}\left(\frac{\text{Var}}{\text{Vr}}\right) \text{dB}$$

where Δ_2 is the quantity in decibels that must be algebraically added to the measured SEL noise level to correct for the influence of the adjustment of the reference airspeed on the duration of the measured flyover event as perceived at the noise measurement station. Vr is the reference airspeed as prescribed under Part II, Chapter 11, 11.5.2, and Var is the adjusted reference airspeed as prescribed in 2.4.1 2.4.2 of this appendix.

6. REPORTING OF DATA TO THE CERTIFICATING AUTHORITY AND VALIDITY OF RESULTS

. . .

6.3 Validity of results

. . .

6.3.2 The sample shall be large enough to establish statistically a 90 per cent confidence limit not exceeding ±1.5 dB(A). No test results shall be omitted from the averaging process unless approved by the certificating authority.

Note.— Methods for calculating the 90 per cent confidence interval are given in ~~Appendix 1 of the~~ ~~Environmental Technical Manual on the Use of Procedures in the Noise Certification of Aircraft~~ *~~(~~Doc 9501~~)~~, Volume I concerning the calculation of confidence intervals.*

. . .

See Work Item N. 16

APPENDIX 6. ~~NOISE~~ EVALUATION METHOD FOR NOISE CERTIFICATION OF PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8 618 kg — ~~APPLICATION FOR TYPE CERTIFICATE SUBMITTED ON OR AFTER 17 NOVEMBER 1988~~ Application for Type Certificate or certification of Derived Version submitted on or after 17 November 1988

. . .

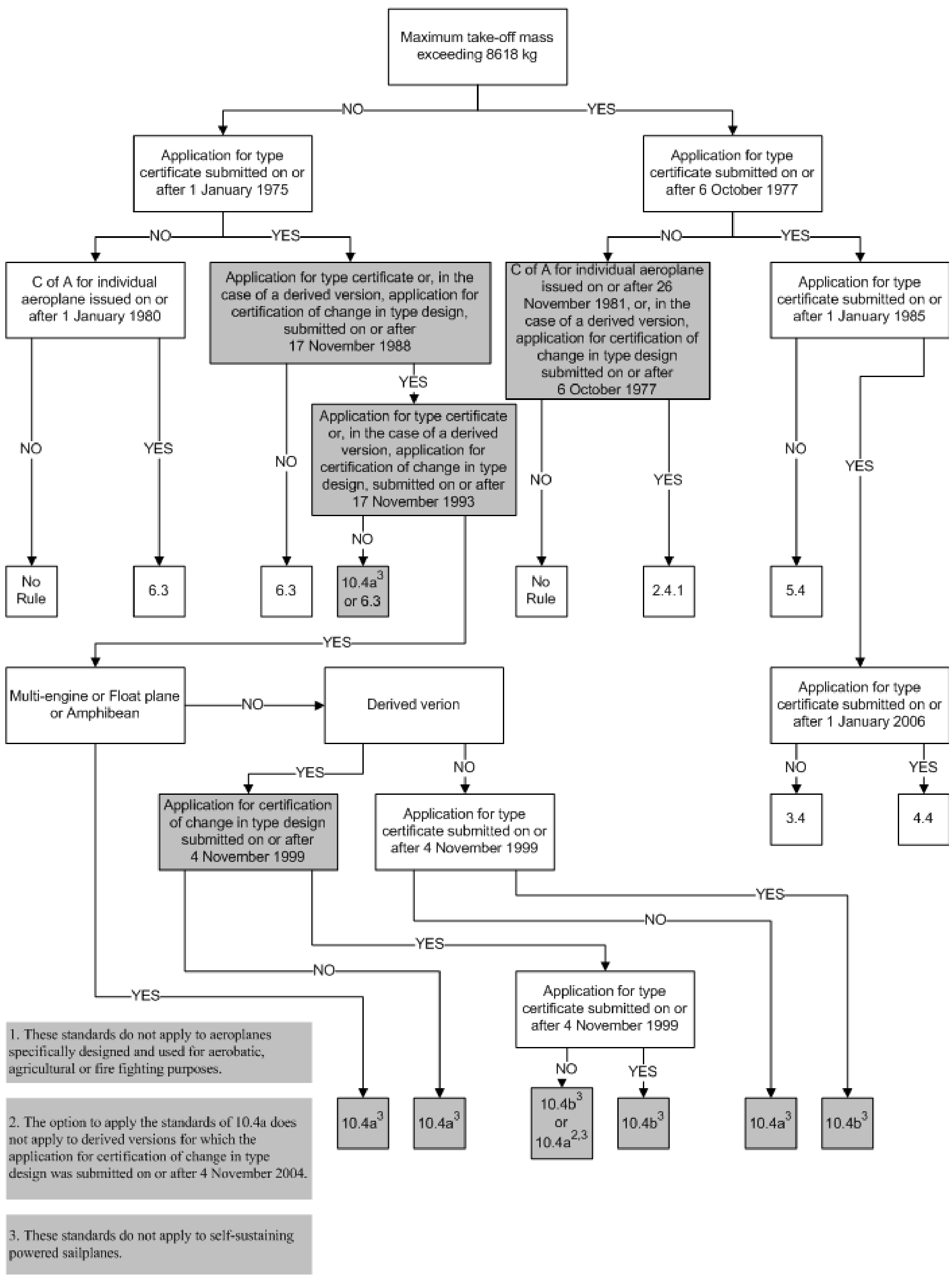
See Work Item N. 16

ATTACHMENTS TO ANNEX 16, VOLUME I

. . .

Replace Attachment E as follows:

ATTACHMENT E. APPLICABILITY OF ANNEX 16 NOISE CERTIFICATION STANDARDS FOR PROPELLER-DRIVEN AEROPLANES[1]



See CAEP-SG/20071-SD/3, 6.16

ATTACHMENT F. GUIDELINES FOR NOISE CERTIFICATION OF TILT-ROTOR AIRCRAFT

Note.— See Part II, Chapter 13.

. . .

6. NOISE CERTIFICATION REFERENCE PROCEDURES

. . .

6.1.6 In 6.2 d), 6.3 d) and 6.4 c), the maximum normal operating rpm should be taken as the highest rotor speed for each reference procedure corresponding to the airworthiness limit imposed by the manufacturer and approved by the certificating authority. Where a tolerance on the highest rotor speed is specified, the maximum normal operating rotor speed should be taken as the highest rotor speed about which that tolerance is given. If the rotor speed is automatically linked with the flight condition, the maximum normal operating rotor speed corresponding with ~~that~~ the reference flight condition should be used during the noise certification procedure. If the rotor speed can be changed by pilot action, the ~~highest~~ maximum normal operating rotor speed specified in the flight manual limitation section for ~~power-on conditions~~ the reference conditions should be used during the noise certification procedure ~~for the corresponding flight condition~~.

. . .

— — — — — — — —

APPENDIX B

ENVIRONMENTAL TECHNICAL MANUAL
ON THE USE OF PROCEDURE IN THE CERTIFICATION OF AIRCAFT NOISE AND AIRCRAFT ENGINES

DOC 9501, VOLUME I - PROCEDURES IN THE NOISE CERTIFICATION OF AIRCRAFT

TABLE OF CONTENTS

INDEX OF GUIDANCE MATERIAL (GM) AND ACCEPTABLE MEANS OF COMPLIANCE (AMC)

LIST OF FIGURES

FOREWORD

F.1 PURPOSE

The aim of this manual is to promote uniformity of implementation of the technical procedures of Annex 16 – Environmental Protection, Volume I – Aircraft Noise, and to provide guidance to certificating authorities and applicants regarding the intended meaning and stringency of the current Annex and those specific procedures that are deemed acceptable in demonstrating compliance to these Standards.

This manual provides guidance material relating to the requirements of Appendices 2, 3, 4 and 6 of the Annex as appropriate. These appendices describe the noise evaluation methods for compliance with the corresponding chapters of the Annex for jet aeroplanes, propeller-driven heavy and light aeroplanes and helicopters.

F.2 DOCUMENT STRUCTURE

The basic framework of this manual is structured to provide various forms of noise certification guidance material for these aircraft. Chapter 1 provides general information, Chapter 2 provides guidance that is common to more than one type of aircraft and subsequent chapters provide guidance unique to different aircraft types.

The general format of the guidance material presented in Chapters 3 through 7 includes three types of information described as Explanatory Information, Equivalent Procedures and Technical Procedures. The definitions of the three types of information are described in the following sections.

F.3 EXPLANATORY INFORMATION

Explanatory information has the following purpose:

- Explains Annex Noise Standards language;
- States current policies of regulatory authorities regarding compliance with the Annex; and
- Provides awareness of critical issues for approval of applicants’ compliance methodology proposals;

Explanatory information may take the form of either:

- Guidance Material (GM) which helps to illustrate the meaning of a specification or requirement; or
- Acceptable Means of Compliance (AMC) which illustrates a means, but not the only means, by which a requirement specified in Annex 16, Volume I, can be met. It may contain reference to an Equivalent Procedure described in this Manual.

The AMC and GM numbers refer to the Appendix and section number of Annex 16, Volume I, to which they relate. For example ***GM A2 2.2.1*** is guidance material concerning section 2.2.1 of Appendix 2 of Annex 16, Volume I.

Bracketed GM and AMC titles denote the general subject matter of the text, and not specific Annex 16 titles. For example **[Test Site Selection]**.

F.4 EQUIVALENT PROCEDURES

An equivalent procedure is a test or analysis procedure which, while differing from one specified in the Annex, in the technical judgement of the certificating authority yields effectively the same noise levels as the specified procedure.

Equivalent procedures fall into two broad categories:

- those which are generally applicable; and
- those which are applicable to a particular aircraft type. For example, some equivalencies dealing with measurement equipment may be used for all types of aircraft, but a given test procedure may only be appropriate for jet aeroplanes and not for turboprop aeroplanes.

Typical applications of equivalent procedures requested by applicants are:

- to use previously acquired certification test data for the aircraft type;
- to permit and encourage more reliable demonstration of small level differences among derived versions of aircraft; and
- to minimize the costs of demonstrating compliance with the requirements of the Annex by keeping aircraft test time, airfield usage, and equipment and personnel costs to a minimum

F.5 TECHNICAL PROCEDURES

A technical procedure is a test or analysis procedure not defined in detail in the Annex but which certificating authorities have approved as being acceptable for compliance with the general provisions of the Annex.

Procedures described in the Annex must be used unless an equivalent procedure or alternative technical procedure is approved by the certificating authority. Procedures should not be considered as limited only to those described herein, as this manual will be expanded as new procedures are developed. Also, their presentation does not infer limitation of their application or commitment by certificating authorities to their further use.

F.6 CONVERSION OF UNITS

Conversions of some non-critical numerical values between Imperial and SI units are shown in the context of acceptable approximations.

F.7 REFERENCES

Unless otherwise specified references throughout this document to “the Annex” relate to Annex 16 to the Convention on International Aviation (Environmental Protection), Volume I (Aircraft Noise), 5th Edition, Amendment 9.

Internal references to sections within this manual are defined only by the section number to which they refer.

External references to documents other than the Annex are numbered in sequence (e.g. Reference 1, Reference 2 etc.).

These external references are as follows:

1. NMEA 0183, Version 1.5 (December 1987). *Standards for Interfacing Marine Electronics Devices*. National Marine Electronics Association.

2. NMEA 0183, Version 2.0 (1 January 1992). *Standards for Interfacing Marine Electronics Devices*. National Marine Electronics Association.

3. Paper 194-93/SC104-STD, Version 2.1 (January 1994). *Recommended Standards for Differential Navstar GPS Service*. Radio Technical Commission for Maritime Services.

4. Parkinson, B.W., and Spilker, J.J. (eds) (1996). *Global Positioning System: Theory and Applications*, Volume I. American Institute of Aeronautics and Astronautics.

5. COMDTINST M16577.1 (April 1993). Broadcast *Standard for the USCG DGPS Navigation Service*. U.S. Coast Guard.

6. DO-229 C (28 November 2001). *Minimum Operational Performance Standards for Global Positioning System/Wide Area Augmentation System Airborne Equipment*. Radio Technical Commission for Aeronautics.

7. Mami Ueno, Kazuaki Hoshinoo et al. *Assessment of Atmospheric Delay Correction Models for the Japanese MSAS*. Proceedings of ION GPS (2001). http://gauss.gge.unb.ca/papers.pdf/iongps2001.ueno.pdf

8. IEC 61265 (1995-04). *Electroacoustics - Instruments for measurement of aircraft noise - Performance requirements for systems to measure one-third-octave band sound pressure levels in noise certification of transport-category aeroplanes*. Bureau Central de la Electrotechnique Internationale.

9. IEC 61260 (1995-07). *Electroacoustics - Octave-band and fractional-octave-band filters*. Bureau Central de la Electrotechnique Internationale.

10. Aerospace Recommended Practice ARP 1846A (2008-03). *Measurement of Far Field Noise from Gas Turbine Engines During Static Operation*. SAE International.

11. Aerospace Recommended Practice ARP 866A (1975-03). *Standard Values of Atmospheric Absorption as a Function of Temperature and Humidity*. SAE International.

12. Aerospace Information Report AIR 1672B (1983-06). *Practical Methods to Obtain Free-Field Sound Pressure Levels from Acoustical Measurements Over Ground Surfaces*. SAE International.

13. Data Item No. 94035 (Amendment A) (December 1995). *The correction of measured noise spectra for the effects of ground reflection*. ESDU International plc.

14. Aerospace Recommended Practice ARP 876E (2006-02). Gas *Turbine Jet Exhaust Noise Prediction*. SAE International.

15. Aerospace Information Report AIR 1905 (1985-12). *Gas Turbine Coaxial Exhaust Flow Noise Prediction*. SAE International.

16. Tester, B. J. and Szewczyk,V. M. Jet *Mixing Noise: Comparison of Measurement and Theory*. American Institute of Aeronautics and Astronautics Paper 79-0570.

17. Laufer, J., Kaplan, R. E. and Chu, W. T.. Noise *Produced by Subsonic Jets*. Proceedings of the Second Inter-Agency Symposium on University Research in Transportation Noise (1974) Volume 1, pp. 50-58.

18. Fink, M. R. (29 March 1977). *Airframe Noise Prediction Method*. USA DOT Report FAA-RD-77-29 Washington, DC.

19. Aerospace Information Report AIR 5662 (2006-04). *Method for Predicting Lateral Attenuation of Airplane Noise*. SAE International.

20. IEC 61672-1 (2002). *Electroacoustics - Sound Level Meters*. Bureau Central de la Electrotechnique Internationale.

Chapter 1

GENERAL GUIDELINES

1.1 APPLICABILITY OF CURRENT AND PREVIOUS AMENDMENTS OF ANNEX 16, VOLUME I

Since the publication of the first edition of Annex 16 many amendments and new editions have been published. Each amendment and new edition retains the older chapters (e.g. Chapter 2), even though these older chapters may no longer be applicable to new types. As each new amendment or edition succeeds the previous version the applicability provisions of each chapter are in principle retained, thus preserving their continuity.

The first section of Chapters 2, 3, 4, 5, 6, 8, 10, 11 and 12 of the Annex, together with the paragraphs concerning applicability in Chapter 1 of the Annex, define the applicability of each chapter. Their applicability to new types is determined by the date the application for the Type Certificate was submitted to the State of Design.

In many instances the Chapter and maximum noise levels so determined for a new type are also applicable to its derived versions (e.g. the applicability provisions of Chapter 3 refer to "all….aeroplanes, including their derived versions").

In some cases the applicability provisions apply only to derived versions (e.g. Chapter 8, 8.1.3). In these cases the applicability provisions are determined by the date the application for certification of the change in type design was submitted to the certificating authority of the Contracting State that first certificated the change in type design.

Note. — The applicability provisions for derived versions are not dependent on how the associated change, or changes, in type design came about (e.g. amended Type Certificate or Supplemental Type Certificate).

The authority of the State of Design or, in the case of derived versions, the original certificating authority, should ensure that the demonstration of compliance is in accordance with the procedures and recommended practices that are described in the amendment of Annex 16 that is applicable at the date of submission for either the Type Certificate or approval of the change in type design as required by Chapter 1 paragraphs 1.10 through 1.13.

Note. — Changes to test procedures and evaluation methods are usually approved by CAEP on the basis that they are "stringency neutral".

The question arises as to what is the status of these approvals as each new amendment of the Annex is published.

a) For the authority of the State of Design in the case of new types, or the original certificating authority in the case of derived versions, the approved noise certification levels corresponding to the amendment of the Annex and revision of this manual that were applicable at the time the application for approval was submitted remain valid and should not be re-assessed against any changes there might be in later amendments or revisions.

b) Many applications for a Type Certificate or for approval of a change in type design are submitted to authorities other than that of the State of Design or original certificating authority. Often these applications are submitted several years after their submittal to the first certificating authority. During this period many new amendments of the Annex and corresponding revisions of this manual may have been published. In the case of an application for a Type Certificate, the applicable Standards are determined according to the provisions of paragraphs 1.10 and 1.11 of Annex. In the case of an application for the approval of a change in type design the applicable Standards are determined according to the provisions of paragraphs 1.10 and 1.11 or 1.12, whichever is applicable, of the Annex.

For an authority to whom these later submittals are made the acceptable means of compliance, technical procedures and equivalent procedures would be those described in the amendment of the Annex and revision of this manual that is applicable at the time the applications are submitted to this authority. The applicability provisions of each chapter do not change over time. However the reference and test procedures and the evaluation methods defined in the appendices do, on occasions, change with each new amendment or edition. An applicant may propose, with supporting justification, to the certificating authority to accept means of compliance and demonstration procedures described in earlier amendments of Annex 16 and equivalent procedures described in earlier revisions of this manual on the basis that they are equivalent to the currently applicable ones.

Note. — Bilateral arrangements between contracting states will facilitate the mutual recognition of approvals granted by certificating authorities of the State of Design by other certificating authorities.

1.2 CHANGES TO AIRCRAFT TYPE DESIGNS INVOLVING "DERIVED VERSIONS"

Many of the equivalent procedures given in this manual relate to derived versions where the procedure used yields the information needed to obtain the noise certification levels of the derived versions by adjusting the noise levels of the "flight datum" aircraft (i.e. the most appropriate aircraft for which the noise levels were measured during an approved flight test demonstration).

The physical differences between the "flight datum" aircraft and the derived version can take many forms, such as an increased take-off mass, an increased engine thrust, changes to the power plant or propeller or rotor types, etc. Some of these differences will alter the distance between the aircraft and the noise certification reference points, others the noise source characteristics. Procedures used in the determination of the noise certification levels of the derived versions will therefore depend upon the change to the aircraft being considered. However, where several similar changes are being made, such as the introduction of engines from different manufacturers, the procedures used to obtain the noise certification levels of each derivative aircraft should be followed in identical fashion.

1.3 CHANGES TO AIRCRAFT TYPE DESIGNS INVOLVING "NO-ACOUSTICAL CHANGES"

Aircraft/engine model design changes and airframe/engine performance changes may result in very small changes in aircraft noise certification levels that are not acoustically significant. These changes are referred to as no-acoustical changes (NACs). For this Manual NACs, which do not result in modification of an aircraft's noise certification levels, are defined as:

a) changes in aeroplane noise certification levels approved by the certificating authority which do not exceed 0.1 dB at any noise measurement point and which an applicant does not track;

b) cumulative changes in aeroplane noise certification levels approved by the certificating authority whose sum is greater than 0.1 dB but not more than 0.3 dB at any noise measurement point and for which an applicant has an approved tracking procedure;

c) for helicopters certificated according to the Standards of Chapter 8 of the Annex changes in any one of the noise certification levels approved by the certificating authority which do not exceed 0.3 EPNdB; and

d) for helicopters certificated according to the Standards of Chapter 11 of the Annex changes in the noise certification level approved by the certificating authority which do not exceed 0.3 dB(A).

With respect to the tracking procedure referred to in b), noise certification approval has been given based upon the following criteria:

a) ownership by the certification applicant of the noise certification database and tracking process on an aircraft/engine model basis;

b) when the 0.3 dB cumulative change in aeroplane noise certification level is exceeded, compliance with the Annex requirements is required. The aircraft certification noise levels may not be based upon summation of NAC noise increments;

c) decreases in noise level should not be included in the tracking process unless the type design change will be retrofitted to all aircraft in service and included on newly produced aircraft;

d) aircraft/engine design changes resulting in noise level increases should be included in the tracking process regardless of the extent of retrofit to aircraft in service;

e) tracking of an aircraft/engine model should, in addition to engine design changes, include airframe, and performance changes;

f) tracked noise increments should be determined on the basis of the most noise sensitive condition and be applied to all configurations of the aircraft/engine model;

g) the tracking should be revised to account for a tracked design change increment that is no longer applicable;

h) changes should be tracked to two decimal places (i.e. 0.01 dB). Round-off shall not be considered when judging a NAC (e.g. 0.29 dB = NAC; 0.30 dB = NAC; 0.31 dB = acoustical change); and

i) an applicant should maintain formal documentation of all NACs approved under a tracking process for an airframe/engine model. The tracking list will be reproduced in each noise certification dossier demonstration.

Due to the applicability dates for Chapters 6 and 10 of the Annex some light-propeller driven aeroplanes are not required to have certification noise levels. However some modifications to these aircraft can be applied which may impact the noise characteristics. In this case, the NAC criterion application should be treated with a procedure approved by the certificating authority.

Noise certification approval of modified helicopters should be granted according to the following criteria:

a) An NAC approval for a derived version shall be made only if the "flight datum" helicopter was flight tested to obtain the certification noise levels;

b) Noise levels for a helicopter designated as a NAC design cannot be used as the "flight datum" for any subsequent design changes; and

c) For changes exceeding the 0.3 dB, compliance with the Annex requirements may be achieved either by testing or, subject to the approval of the certificating authority, by analytical means. If analytical means are employed, the noise certification levels cannot be used as the "flight datum" for any subsequent design changes.

A flowchart illustrating the criteria for dealing with modified helicopters is presented in Figure 1-1.

Due to the applicability dates for Chapters 8 and 11 of the Annex some helicopters are not required to have certification noise levels. However some modifications to these helicopters can be applied which may impact the noise characteristics. In this case, the NAC criterion application should be treated with a procedure approved by the certificating authority.

1.3.1 Modifications to helicopters for which changes in noise level(s) need not be determined

a) Chapters 8 (8.1.5) and 11 (11.1.5) of the Annex require that "certification of helicopters which are capable of carrying external loads or external equipment shall be made without such loads or equipment fitted".

It follows that changes in noise level(s) arising from modifications associated with the installation or removal of external equipment need not be determined. For the purposes of this paragraph "external equipment" means any instrument, mechanism, part, appurtenance, or necessary accessory that is attached to, or extends from, the helicopter exterior but is not used, nor is intended to be used, in operating or controlling the helicopter in flight and is not part of an airframe or engine.

b) In this respect the following are considered to be no-acoustical changes:

– The addition or removal of external equipment;

– Changes to the airframe made to accommodate the addition or removal of external equipment, to provide for an external load attaching means, to facilitate the use of external equipment or external loads, or to facilitate the safe operation of the helicopter with external equipment mounted to, or external loads carried by, the helicopter;

– Reconfiguration of the helicopter by the addition or removal of floats and skis;

– Flight with one or more doors and/or windows removed or in an open position; or

– Any changes in the operational limitations placed on the helicopter as a consequence of the addition or removal of external equipment, floats, skis, or flight operations with doors and/or windows removed or in an open position.

1.4 RECERTIFICATION

Recertification is defined as the "certification of an aircraft, with or without revision to noise levels, to a Standard different to that which it had been originally certificated".

In the case of an aircraft being recertificated from the Standards of Chapters 3 or 5 of the Annex to Chapter 4 noise recertification should be granted on the basis that the evidence used to determine compliance is as satisfactory as the evidence associated with a new type design. The date used by a certificating authority to determine the recertification basis should be the date of acceptance of the first application for recertification.

The basis upon which the evidence associated with applications for recertification should be assessed is presented in Chapter 8.

1.5 NOISE COMPLIANCE DEMONSTRATION PLANS

Prior to undertaking a noise certification demonstration the applicant is normally required to submit to the certificating authority a noise compliance demonstration plan. This plan contains a complete description of the methodology and procedures by which an applicant is proposing to demonstrate compliance with the noise certification standards specified in the Annex. Approval of the plan and the proposed use of any equivalent procedures or technical procedures not included in the Annex remains with the certificating authority.

Noise compliance demonstration plans should include the following types of information:

a) Introduction

A description of the aircraft noise certification basis, i.e. the applicable Amendment and Chapter of the Annex.

b) Aircraft description

Type, model number and the specific configuration to be certificated.

Note.- The certificating authority will normally require that the applicant demonstrates and documents the conformity of the test aircraft and/or engine, particularly with regard to those parts which might affect its noise characteristics.

c) *Aircraft noise certification methodology*

Test concepts, equivalent procedures and technical procedures.

– For example, the certification of Chapter 3 or 4 aeroplane families (a form of derived versions) often require approval of equivalent procedures involving measurement and evaluation of static engine noise test data These procedures include projection of static engine noise test data for development of flyover, lateral, and approach Noise-Power-Distance (NPD) plots that define differences between the aeroplane used for the original noise certification flight test and a derived version;

– Applicants have also proposed taking advantage of program availability of an aeroplane engine by acquiring static engine noise test data for potential future noise certification applications; and

– Another example of a more general nature involves aircraft type design changes (e.g. mass/thrust, airframe design changes or minor changes in engine components or acoustical treatments), where applicants have proposed using analytical equivalent procedures to derive noise increments to an aircraft's certification noise levels or to demonstrate a NAC between the original certificated aircraft and the derived version.

c) *Plans for tests*

The plans for test should include:

– Test description

Test methods to comply with the test environment standards and flight path measurement standards of Appendices 2, 3, 4, or 6 of the Annex, as appropriate, and the applicable takeoff and approach reference procedures of the chapters of the Annex appropriate to the aircraft type being certificated.

– Measurement system

Description of measurement system components and procedures including calibration procedures that comply with the standards of Appendices 2, 3, 4, or 6 of the Annex, as appropriate, and proposed systems and procedures for meteorological and time/space position measurements.

– Data evaluation procedures

Noise evaluation and adjustment procedures, including equivalent and technical procedures provided in this manual, to be used in compliance with the provisions of Appendices 2, 3, 4, or 6 of the Annex, as appropriate to the aircraft type being certificated.

Note.- Plans for tests should either be integrated into the basic noise compliance demonstration plan, or submitted separately and referenced in the basic plan.

1.6 NOISE CERTIFICATION REPORTS

After completion of a noise certification demonstration test an applicant is normally required to submit a noise certification report. This report provides a complete description of the test process and the test results with respect to compliance with the provisions of the Annex Noise Standards for the aircraft type being certificated.

These reports should include the following types of information:

a) *Basis for test approval*

Identify the approved noise certification compliance plan for the aircraft type and model being certificated;

b) *Description of tests*

Actual configurations tested (aircraft, engines, or components), non-conforming items (with justification that they are not acoustically significant or if significant can be dealt with by an approved method), test methodology (including equivalent procedures and technical procedures), tests conducted, test data validity, and data analysis and adjustment procedures used;

c) *Test results*

Provide data to demonstrate compliance with the provisions of the Annex regarding maximum noise levels and 90 per cent confidence limits for the aircraft type being certificated; and

d) *References*

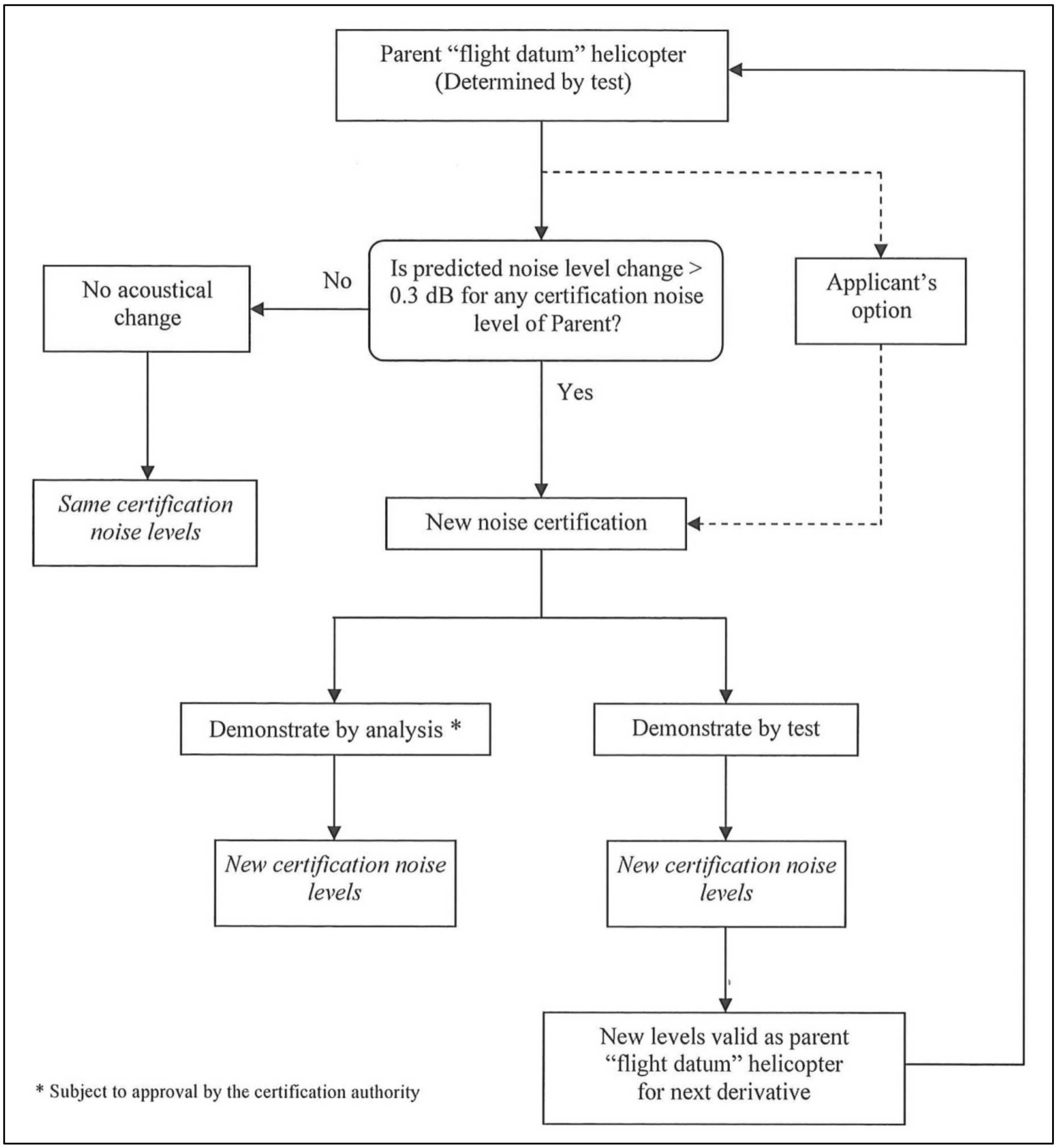


Figure 1-1 "No acoustical change" criteria for modifications to noise certificated helicopters

Chapter 2

TECHNICAL PROCEDURES APPLICABLE FOR NOISE CERTIFICATION OF MORE THAN ONE TYPE OF AIRCRAFT

2.1 TEST SITE SELECTION

For aeroplanes, when the flight path intercept test procedure is used, and for helicopters, it may not be necessary for the test site to be located at an airport. Details of proposed noise certification test site locations should be submitted to the certificating authority for review and approval. Some test site criteria that could support selection of a non-airport test site include level terrain, reduced air traffic, reduced ambient noise, improved weather conditions (temperature, humidity and wind), improved microphone placement, availability of field surveys, improved locations for aircraft position monitoring and improved pilot sight and handling.

2.1.1 Terrain

Uneven terrain having features such as mounds or furrows can result in reflections that could influence the measured sound levels. Vegetation can reduce the amount of sound that is reflected from the ground surface. In most cases this effect results in a reduced sound level, but under some circumstances the level may be higher. Testing over a smooth hard surface, such as a paved area will generally result in a higher sound level.

2.1.2 Grass

For noise measurement points under the flight path 7.5 m (25 ft) radius circles of mowed grass (not exceeding 8 cm (3 in) height) are acceptable. For noise measurement points located to the side of the flight path, the grass may be mowed in a semicircle 7.5 m (25 ft) radius) facing the line of flight.

2.1.3 Snow

Snow in the area surrounding the noise measurement points may provide excessive absorption of aircraft sound reflected from the ground. Noise measurement points have been approved when snow within a 15 m (50 ft) radius of the noise measurement points has been removed. However, snow should not be piled at the borders facing the line of flight.

2.1.4 Plowed Fields

Earthen or sandy surfaces within a 7.5 m (25 ft) radius of the noise measurement points shall be reasonably tamped down. Plowed furrows, silt, or soft powdered surfaces are unacceptable.

2.1.5 Obstructions

Obstructions in the vicinity of the noise measurement points such as buildings, walls, trees, vehicles, and test personnel, if close enough, may be unacceptable because of reflections that influence measured noise levels.

There should be no obstructions that significantly influence the sound field from the aircraft within a conical space above a point on the ground vertically below the microphone at each noise measurement point. The cone is defined by an axis normal to the ground and by a half angle of 80º (75º for light propeller driven aeroplanes) from the axis as illustrated in Figure 2-1.

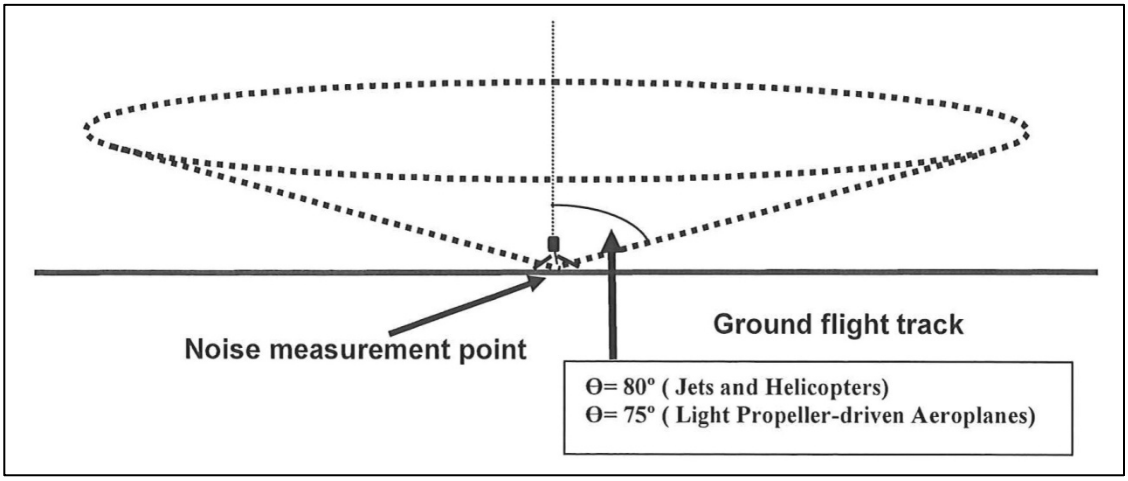


Figure 2-1 Obstruction-free cone defined from the base of the measurements microphone

2.2 FLIGHT PATH MEASUREMENT

The criteria for the measurement of aircraft height and lateral position relative to the intended track are described in 2.3 of Appendices 2, 3, 4 and 6 of the Annex. Examples of methods used include:

a) radar tracking system;

b) theodolite triangulation;

c) photographic scaling; and

d) Differential Global Positioning System (DGPS) based time-space-position information tracking systems.

Practical examples of aircraft tracking systems employing one or more of these techniques are described in subsequent sections. Other tracking systems such as inertial navigation systems (INS) and microwave systems which have a high degree of accuracy have been installed in aircraft and consequently have been accepted by several certificating authorities for use during noise certification. These techniques may be used singly or in combination.

This material is not intended to be an exhaustive list and additional information will be included as more experience is acquired.

2.2.1 Radar or microwave tracking system

One example of a radar position tracking system is shown in Figure 2-2. It operates on a principle of the pulse radar with a radar interrogator (receiver/transmitter) located on the aircraft and a radar transponder (receiver/transmitter) positioned at each reference station. The elapsed time between the receiver/transmitter pulse and reception of the pulse returned from the reference station transponder is used as the basis for determining the range of each reference station. This range information, together with the known location of the reference stations, can be used to obtain a fix on the position of the aircraft in three dimensions.

A pulse coding system is employed to minimise false returns caused by radar interference on reflected signals. The system performs the following basic functions during noise certification:

a) continuously measures the distance between the aircraft and four fixed ground sites;

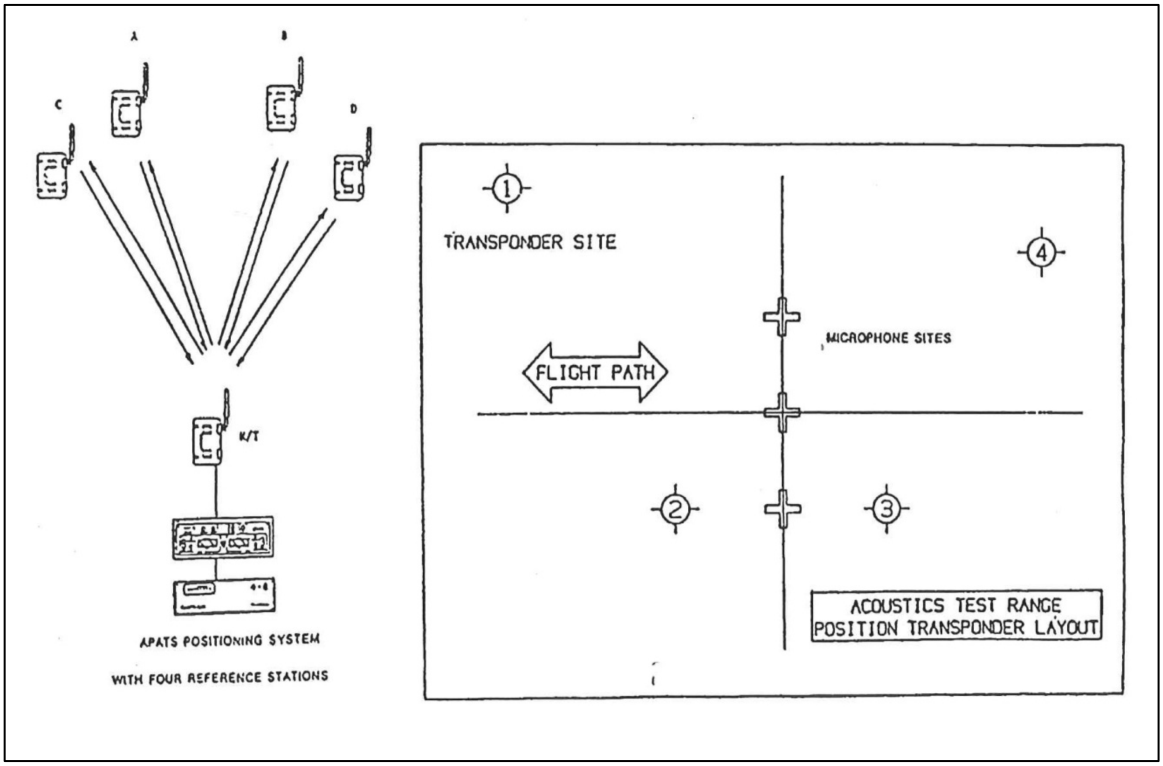


Figure 2-2 Example Radar/microwave position tracking system

b) correlates these ranges with Inter-Range Instrumentation Group Standard Serial Time Code Format B (IRIG B) time code and height information and outputs these data to a pulse code modulation (PCM) recorder;

c) converts the aircraft range and height information into X, Y and Z position co-ordinates in real time; and

d) uses the X, Y, Z data to drive a cockpit display providing the pilot with steering and position cueing.

The accuracy of the co-ordinate calculation depends on the flight path and transponder geometry. Errors are minimised when ranges intersect and the recommended practice is to keep the intersection angle near to 90°. The four transponder arrangements shown in Figure 2-2 produce position uncertainties from ± 1.0 m to ± 2.0 m (± 3 ft to ± 7 ft).

At low aircraft heights some inaccuracies can be introduced with the use of microwave systems. The use of a radio-altimeter can reduce these errors. The height data are recorded and synchronised with the microwave system.

2.2.1.1 ***Aircraft equipment***

The distance measuring unit computer and transponder beacon are connected to a hemispherical antenna which is mounted under the fuselage, on the aircraft centreline, preferably as close to the aircraft centre of gravity as possible.

2.2.1.2 ***Ground equipment***

The four beacons should be located on either side of the aircraft ground track to permit an optimum layout.

For example a helicopter should be covered with angles between 30° and 150° (90° being the ideal angle). Two beacons can be located on the axis of the noise measurement points at distances of ± 500 m (± 1640 ft) from the central microphone, while another two beacons can be located on the track at ± 600 m (± 1969 ft) from the central microphone.

2.2.2 Kine-theodolite system

It is possible to obtain aircraft position data with classical kine-theodolites, but it is also possible to make use of a system composed of two simplified theodolites including a motorised photo-camera on a moving platform, which reports azimuth and elevation. These parameters are synchronized with coded time and the identification number of every photograph recorded.

Each 0.1 s azimuth and elevation data measurement is sent to a central computer which calculates the aircraft position (X, Y and Z) versus time for each trajectory.

For example, for helicopter testing photographic stations should be located at sideline positions about 300 m (984 ft) from the track, and at 200 m (656 ft) on either side of the three noise measurement points.

The accuracy of such a system can be ± 1.5 m (± 4.9 ft) in X, Y and Z over the working area.

2.2.3 Radar / thoedolite triangulation

The opto-electronic system shown diagrammatically in Figure 2-3 uses a single optical theodolite to provide azimuth and elevation while range data are obtained from a radar tracking system using a single transponder. Data from these two sources are transferred to a desk top calculator at a rate of 20 samples/second from which three dimensional position fixes can be derived. The system also provides tape start and stop times to the measuring sites, synchronising all tape recording times. The accuracy of the system is approximately ± 2.0 m (± 6.6 ft), ± 1.0 m (± 3.3 ft) and ± 2.0 m (± 6.6 ft) for horizontal range (X), cross-track (Y) and height (Z) respectively. Uncertainties associated with the determination of the visual glide slope indicator and ground speed are ± 0.1° and ± 0.9 km/h (± 0.5 kt).

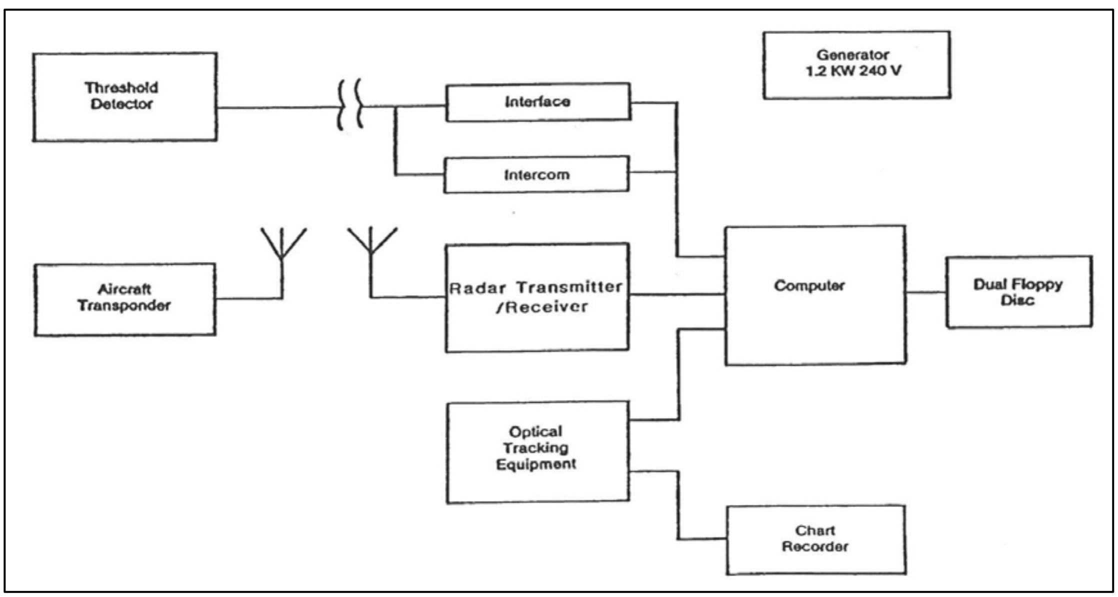


Figure 2-3 Radar/optical position tracking system

2.2.4 Photographic scaling

The flight path of an aircraft during a noise certification demonstration may be determined by using a combination of ground based cameras and height data supplied as a funct ion of time from the on-board radio or pressure altimeters.

For example, using this method for a helicopter, three cameras are placed along the intended track, such that one is sited close to the centre microphone position and the other two sited close to each of the 10 dB-down points, typically 500 m (1640 ft) either side of the microphone, depending upon the flight procedure being used. The cameras are mounted vertically and are calibrated so that the image size, obtained as the helicopter passes overhead, can be used to determine the height of the aircraft. It is important that the time at which each camera fires is synchronised with the on-board data acquisition system so that the height of the aircraft as it passes over each of the cameras can be correlated with the heights obtained from the photographs.

The flight path of the aircraft as a function of distance may be obtained by fitting the aircraft data to the camera heights.

The aircraft reference dimension should be as large as possible in order to maximise photograph image size but should be chosen and used with care if errors in aircraft position are to be avoided. For a helicopter foreshortening of the image due to factors such as main rotor coning (bending of the blades), disc tilt or fuselage pitch attitude, if not accounted for, will result in errors in the measurement of height and/or lateral and longitudinal position.

By erecting a line above each of the cameras at right angles to the intended track, at a sufficient height above the camera in order to provide a clear photographic image of both the line and the aircraft, the applicant may obtain the lateral offset of the aircraft as it passes over each of the cameras. This can be done by attaching marks to the line showing the angular distances from overhead at 5° intervals on either side of the vertical.

For example, for helicopters, this method may be used to confirm that the helicopter follows a 6° ± 0.5° glide slope within 10° of the overhead of the centre microphone as required by 8.7.8 and 8.7.10 of Chapter 8 of the Annex.

Furthermore, from the synchronised times of the aircraft passing over the three camera positions, the ground speed can be determined for later use in the duration adjustment.

Overall accuracy of the system is ± 1.0 per cent of height and ± 1.3 per cent of longitudinal and lateral displacements. Mean approach/climb angles and mean ground speed can be determined within ± 0.25° and ± 0.7 per cent respectively.

2.2.5 DGPS-based time space position information tracking systems

2.2.5.1 General

The use of conventional Global Positioning System (GPS) receivers onboard aircraft to obtain Time-Space-Position Information (TSPI) is not considered to be accurate enough for noise certification testing. However, by using data from a second, localized, fixed-position GPS receiver, a substantial improvement in accuracy can be achieved. Such an arrangement is referred to as a Differential GPS (DGPS) System.

Certificating Authorities may approve the use of such DGPS systems, based on the particular characteristics of the hardware, related software, installation and operational specifics proposed by the applicant. This section summarizes recommended requirements for DGPS systems proposed for use during noise certification testing.

Typically the hardware components of these systems are GPS receivers and antennae on the ground and in the aircraft, data link transmitter and antenna on the ground and corresponding receiver and antenna in the aircraft, a laptop computer in the aircraft and batteries and electronic power supplies (see Figure 2-4). Software, running on the laptop computer in the aircraft, provides the user control/display function and performs data logging. A personal computer is generally needed to initialize the GPS receiver on the ground, but is not necessary for continuous operation.

In addition to generating flight reference data for post processing, some applicants' systems provide the pilot with information to navigate the aircraft. Measured aircraft position is compared to a desired reference flight path, and steering commands are sent to a course/glide slope deviation indicator (CDI/GDI) installed specifically for use with the DGPS system.

Variations on the basic architecture shown in Figure 2-4 are possible. For example, it is possible to eliminate the data link elements by collecting and storing data from both GPS receivers during a flight, and post-processing these data in a single computer after the flight is complete. However, without a data link, DGPS data cannot be used for aircraft guidance, nor can an aircraft-based operator obtain "quick-look" information regarding the DGPS solution quality. Another possible variation on the basic architecture in Figure 2-4 involves the use of a two-way data link. Typically, identical transceivers would be used on the ground and in the aircraft. This enables ground tracking of the aircraft during testing.

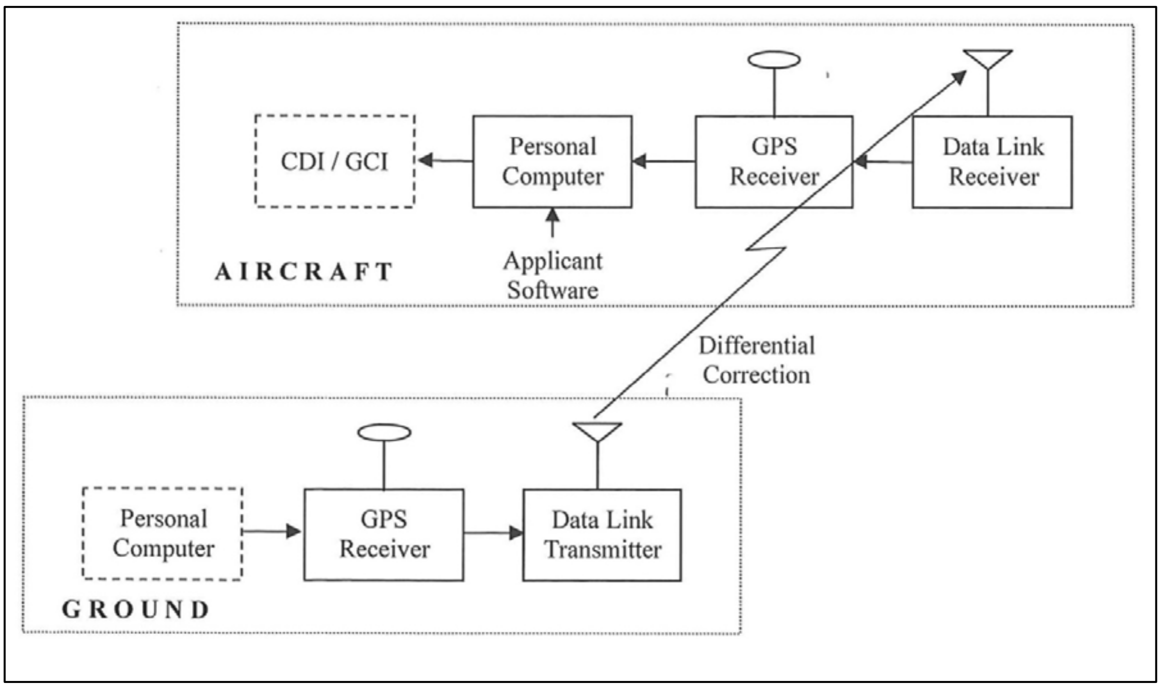


Figure 2-4 DGPS TSPI System Basic Architecture

2.2.5.2 ***System design issues***

This section discusses DGPS system design issues including configuration, airport survey, DGPS receiver output data, and sources of error in DGPS systems.

2.2.5.2.1 Coordinate frames and waypoint navigation

The native coordinate system for GPS (i.e. the one in which its computations are performed) is the World Geodetic Survey of 1984 (WGS-84). Most GPS receivers provide output position information (latitude, longitude and altitude) in a variety of geodetic coordinate systems by transforming the WGS-84 position data.

Aircraft noise certification tests typically involve the use of a rectangular coordinate frame whose definition is based upon the array of microphones or the centre-line of an airport runway. Typically, the frame's x-axis is established from two points on the ground that are nominally aligned with the runway centreline, the y-axis is orthogonal to the x-axis and also level, and the z-axis is vertical. Some GPS receivers can furnish data in a rectangular coordinate system based on waypoints. These are user-defined reference points intended to facilitate navigation along a route or in a local area. If a receiver supports waypoint navigation then two such points, defined in terms of latitude, longitude, and altitude, can be entered into the receiver.[1] The receiver will subsequently provide aircraft position relative to the coordinate frame implicitly defined by the points (i.e. the distance from the line connecting the two points and the distance to one point).

If waypoint navigation is to be used for noise testing, then the initial survey performed to determine the position of the two waypoints is critical to the accuracy of the TSPI results (see 2.2.5.2.2). If waypoint navigation is not available, or is not to be used, then the geodetic position solution (i.e. latitude, longitude and altitude) must be transformed to a local coordinate system through post processing by the applicant prior to noise data processing.

2.2.5.2.2 Test site survey

A careful survey of the airport and nearby areas where noise testing is to be conducted is critical to the success of a measurement program. The following steps are involved in a survey:

a) An initial reference location, including numerical values for its latitude, longitude and altitude, is selected and its coordinates are stored in a permanent file for record keeping. Normally the initial reference location will be a surveyed monument on the airport, upon which latitude and longitude are stamped. Often the monument will have been derived from a third-order survey, in which case geodetic position errors of the order of hundreds of metres are not uncommon. However, such errors have virtually no effect on the measurement of positions relative to that point or another point derived from it. The published airport reference altitude can be assigned to the monument. Although this altitude typically is applicable to the base of the tower, the altitude difference between the monument and tower will not degrade the accuracy of differential measurements relative to the reference location. Many GPS receivers have a "survey" mode whereby they average position measurements over a user-selected period of time (e.g. 24 hours) to generate a surveyed position estimate. Typical resulting absolute accuracies are 0.9 to 3 m (3 to 10 ft), which are more than adequate if the DGPS-based TSPI system measurements will not be related to measurements from another system;[2]

---

[1] For noise certification testing it is recommended that the GPS receiver reads the waypoints from a printable data file. Alternatively, the waypoints could be keyed into the receiver and then written to a data file.

[2] Prior to the advent of satellite-based techniques in the 1990s, land surveys were performed using an optical theodolite (to measure angles) and a chain (to measure linear distance). Networks of interlocking triangles were surveyed, with measurements collected at each vertex. The accuracy of such a survey was classified by the amount that the sum of the interior angles of a triangle deviated from 180º (after accounting for the earth's curvature). A first-order survey was the most accurate; the vertices were typically 16 to 64 km (10 to 40 miles) apart, and the angular error 1 arc second or less. Also, for a first-order survey, the latitude/longitude of one point was measured by astronomical means (accuracy approximately 15 m (50 feet)). A second-order survey had vertices 8 to 16 km (5 to 10 miles) apart and maximum angular error of 5 arc minutes. A third-order survey had vertices 1.6 to 3.2 km (1 to 2 miles) apart and angular error not exceeding 15 arc minutes.

b) The DGPS-based TSPI system, with the ground-station antenna at the initial reference location, is used to measure the coordinates of the location where the ground-station antenna will be installed for the remainder of the test series. The latitude, longitude and altitude of this second location is stored in a permanent file for record keeping. If convenient, the ground-station antenna may be installed at the initial reference location for the duration of the test series;

c) If waypoint navigation is to be used for the measurement program, the DGPS-based TSPI system, with the ground station at the second (i.e. normal) location, is used to measure the latitude, longitude and altitude of the FROM and TO waypoints which will be used to establish the test program coordinate frame. At least three measurements should be made to guard against errors. The resulting locations should be stored in a permanent file for record keeping;

d) The DGPS-based TSPI system, with the ground station at its normal location, is used to measure the microphone positions. The measured positions are stored in a permanent file for record keeping. If waypoint navigation is to be used for the measurement program then microphone positions should be recorded in test coordinates, otherwise latitude, longitude and altitude should be used; and

e) If it is not feasible to use the DGPS-based TSPI system to survey the microphone locations then direct measurements of at least three common points should be performed in order that the relationship between the two surveys can be determined. For example, if the microphones are surveyed using classical techniques then a DGPS-based TSPI survey of the two microphones at the ends of a microphone line and one other microphone, as far removed from the first two as possible, will be sufficient. The surveys should agree to within 30 cm (1 ft) at each common point. If they differ by more than 30 cm (1 ft) and the difference can be expressed in terms of an offset and a rotation, then it may be possible to adjust the results of one survey to agree with the other. Such adjustments should be approved by the certificating authority prior to testing.

The above tests should be performed as a minimum before and after each measurement program. Post-test data analysis should include a comparison of the two surveys.

2.2.5.2.3 <u>Receiver output data</u>

This section addresses the GPS receiver messages[3] (output data) which are of interest. All data are typically furnished via RS-232 serial ports (acceptable GPS receivers generally have multiple RS-232 ports).

Three kinds of GPS receiver output data are of interest:

a) data stored during flight testing, for use during post-test processing of noise data, collected from either the aircraft receiver when a real-time data link is used or from both receivers when a real-time data link is not used;

b) differential correction data output by the ground-station receiver, transmitted to the aircraft via a real-time data link, and input to the aircraft receiver. These data are not stored, but directly influence the accuracy of the stored data addressed in a); and

c) data collected from the ground-station GPS receiver during multi-path verification tests prior to flight testing.

2.2.5.2.3.1 <u>*Data stored during aircraft noise testing when real-time data link used*</u>

GPS receivers provide TSPI data in a variety of formats, both industry-standard and proprietary. In the United States, the National Marine Electronics Association (NMEA) has issued standards (References 1 and 2) which are intended to facilitate user communications with GPS receivers and other navigation devices. Some GPS manufacturers have adopted NMEA standards, some use proprietary formats, and some use both. Those

[3] Standards organizations and manufacturers employ different terminology for pre-defined groups of data parameters available from receiver output ports. For example, in the U.S., the National Marine Electronics Association (NMEA) uses the term “sentences,” the Radio Technical Commission for Maritime Services (RTCM) uses “messages,” Novatel Communications uses “logs,” and Trimble Navigation Ltd. uses “Cycle Printouts.”

manufacturers that provide NMEA outputs generally only implement a subset of the full set of messages set forth in the standards, and some follow the older Version 1.5 (Reference 1) rather than Version 2.0 (Reference 2), upon which this guidance was based.

GPS receiver manufacturers have chosen different parameters to indicate the quality or status of the TSPI data. DGPS-based TSPI systems considered for noise certification tests, using a real-time data link, should save data from the aircraft GPS receiver in the receiver's native raw format in permanent files for record keeping. Stored data should include time (e.g. Universal Time Code (UTC) or GPS time with or without a local offset), aircraft latitude, longitude and altitude, or equivalently, aircraft position relative to a pre-defined waypoint, together with a status or quality flag indicating the reliability of the DGPS solution.

Typically the applicant will employ post-processing software which will read the raw data, parse and format these data, perform any necessary transformations, and generate a file which will be used for noise data processing. Storage of raw data allows the certificating authority to verify the validity of the post-processed results.

2.2.5.2.3.2 *Data stored during aircraft noise testing when real-time data link not used*

DGPS-based TSPI systems considered for noise certification tests which do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw (i.e. the receiver's native) format in permanent files for record keeping. Manufacturers' proprietary formats should be used since NMEA standard messages do not support this application.

For post-processing, stored data should include time (e.g. UTC or GPS time) with or without a local offset, satellite ephemeris (see 2.2.5.2.6.4 for a discussion of satellite ephemeris/clock data), pseudoranges[4], signal-to-noise ratios[5], and carrier phase.[6] Applicants using dual-frequency (L1/L2) receivers will typically also save L2 carrier phase data.[7] Typically, post-processing of the ground-based and airborne GPS data will be performed using manufacturer-supplied software. If this is not the case, then any applicant-developed software should be approved by the certificating authority.

2.2.5.2.3.3 *Real-time DGPS messages:*

GPS receiver manufacturers have implemented both industry-standard and proprietary messages for use on real-time DGPS data links. The Radio Technical Commission for Maritime Services (RTCM), Special Committee 104 (SC-104) has issued a standard (Reference 3) that is followed by most manufacturers. Manufacturers usually implement only a subset of the RTCM/SC-104 messages, and some follow the older Version 2.0 of Reference 3 rather than Version 2.1, upon which this guidance was developed. Some manufacturers have also implemented proprietary DGPS messages which these frequently bear a close resemblance to the RTCM/SC-104 messages.

For applicants implementing a real-time DGPS data link, it is preferred that RTCM/SC-104 messages be employed for this purpose. Type-1 or Type-9 messages, each of which contains the actual DGPS corrections, should be selected and transmitted at a rate of 0.5 Hz or higher. Other message types (e.g. Type-3 ground-station location and Type-5 satellite health) may be used, but should be sent at a rate of once per minute or slower. There is no

---

[4] Pseudorange is the receiver's measured distance to a satellite, and is derived from the coarse/acquisition (C/A) code. It includes a receiver clock bias error, and may be quantified in units of time or distance.

[5] Signal-to-noise ratio (also called carrier-to-noise ratio) is derived from the receiver's tracking loop circuits, and is a measure of the received signal strength. It is usually quantified in dB-Hz, and varies from approximately 33 to 50.

[6] Carrier phase is the amount of carrier cycles (at 1,575.42 MHZ) which have accumulated since logging of this parameter was begun. It may be quantified in radians, degrees, cycles, or feet (to convert to cycles, divide by the wavelength, 0.6247 feet).

[7] The highest accuracy DGPS systems employ the signal carrier (L2=1,575.42 MHZ), rather than the code (L1=1.023 MHZ) which modulates the carrier, as the basic measurement observable. These techniques require that the number of full carrier cycles, i.e., 8 inch wavelengths, between the ground station and aircraft be determined once during a test. After the cycle count is established, the ground-station/aircraft-separation is tracked to fractions of a wavelength, provided that the receiver carrier tracking loops (circuits) maintain phase lock.

recommended requirement for storing real-time DGPS correction data. The data status or quality flag (see 2.2.5.2.3.1) should however provide an indication that the correction data has been properly received and processed by the aircraft.

2.2.5.2.3.4 *Messages for multi-path testing*

Applicant-designed systems using code-based DGPS processing should collect and save data from dedicated multi-path tests to be conducted prior to aircraft noise testing (see 2.2.5.2.5). Data collected during multi-path tests should include individual satellite pseudo-ranges and signal-to-noise ratios. These parameters are only provided by receiver manufacturers' proprietary messages. It is not necessary for applicants to conduct a dedicated test for systems using carrier-based DGPS processing.

2.2.5.2.4 System accuracy and sources of DGPS error

If only divergence (spherical spreading) of the noise is considered, and atmospheric absorption mechanisms are ignored, then a 0.1 dB change in the noise level corresponds to a change of approximately 1.1 per cent of the distance between the aircraft noise source and the measurement microphone. Thus, for an aircraft altitude of 122 m (400 ft), the approximate minimum altitude during noise certification tests, a position error of 1.3 m (4.3 ft) along the line-of-sight vector connecting the microphone and aircraft can be expected to introduce 0.1 dB error in the processed noise data. A position error of 3.0 m (9.8 ft) along the line-of-sight vector can be expected to introduce 0.23 dB error in the processed noise data.

For most DGPS systems, the most important error sources are, in decreasing order of importance, multi-path, correction latency, and tropospheric delay. When these error sources are properly controlled DGPS systems can provide accuracies between a few centimetres and approximately 4.6 m (15.1 ft) for an aircraft in low-dynamics flight regimes. Even the poorest of these accuracies is superior to that achieved by other conventional TSPI systems used for aircraft noise tests, including microwave and photo-scaling. The best accuracies are superior to those for a laser tracker.

DGPS systems suitable for consideration by noise certification applicants can be expected to achieve an accuracy of a few centimetres to 1.5 m. The highest accuracy is achieved using carrier-based techniques and post-flight processing of data collected from both the aircraft and ground-station computers. Code-based solutions which use carrier smoothing (e.g. Novatel RT-20) achieve accuracies of 0.9 m to 1.5 m (3.0 ft to 4.9 ft), provided that the error sources discussed in this section are addressed properly. Consequently it is expected that the DGPS systems used for noise certification tests will introduce less than 0.2 dB error into the noise data in a worst case scenario (i.e. a noise certification approach measurement). Typical errors will be less than 0.1 dB for noise certification flyover and lateral measurements.

In addition to the three error sources cited above, increases in DGPS position errors can also occur when the ground station and aircraft do not have the same manufacturer and model GPS receiver, or when the ground station and aircraft receivers use different satellite ephemeris/clock data to specify the satellite orbital parameters.

Sections 2.2.5.2.5 and 2.2.5.2.6 address all of the above errors, and include methods for minimizing these errors or eliminating them entirely.

2.2.5.2.5 Multi-path errors

2.2.5.2.5.1 *Characteristics*

Multi-path refers to signals from GPS satellites which are reflected from objects (e.g. the ground, buildings, and aircraft structural elements) before reaching the GPS antenna. Multi-path signals add algebraically to the desired line-of-sight signal, and thereby decrease the accuracy of measurements made with the latter. Multi-path conditions can occur independently at the aircraft and ground station antennae. Thus the differential correction data from the ground are not directly useful for correction for multi-path errors at the aircraft antenna. Rather, the broadcast corrections can contain ground station multi-path errors which, in a statistical sense, add to those in the aircraft.

Measurements have consistently shown that the presence of multi-path conditions at the ground station is significantly more deleterious than at the aircraft. This is because ground-station multi-path conditions vary slowly, acting like a bias over a test run of a few minutes, whereas the more dynamic motion of the aircraft causes the effects of airborne multi-path conditions to behave like noise which can be reduced somewhat by processing techniques such as filtering and averaging.

For code-based processing, ground station multi-path error is typically between 0.3 m and 3 m (1.0 ft and 9.8 ft). Under very adverse conditions (e.g. GPS antenna near the side of and well below the top of a large building) multi-path errors can be several hundred metres. Multi-path errors associated with carrier-based processing techniques are significantly less than those for code-based methods, and are usually of the order of centimetres.

The extent of the multi-path error primarily depends on two factors, the capability of the ground station antenna and the location of the ground station antenna relative to reflecting objects such as paved runways, buildings and parked aircraft. Receiver processing (e.g. the use of narrow correlators available in most Novatel receivers) and/or carrier smoothing, available from several manufacturers, can reduce multi-path errors.

2.2.5.2.5.2 Code-Based system ground station

To mitigate the effects of multi-path conditions on DGPS-based TSPI performance, the applicant's ground station installation should meet the following requirements:

a) The ground station should employ a multi-path-limiting antenna, such as one with a choke ring or an absorbing-ground plane; and

b) The ground station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 3 m (9.8 ft) above ground level is recommended for the ground-station antenna.

Additionally, to ensure that significant undetected multi-path errors do not corrupt the TSPI data collected during aircraft noise testing, the applicant's ground-station installation should be tested for adequate multi-path condition performance prior to commencing with the flight test. This can be done by collecting GPS receiver data during the same hours of the day that the system will be used for noise tests, with additional 1 hour buffers on either side of this period. The data is then examined on a per-satellite basis, rather than navigation solution basis, for multi-path signatures. This examination should include at least pseudo-ranges and signal-to-noise ratios. Reference 4 (beginning on Page 560) gives a procedure for examining GPS data for multi-path.

If multiple periods of significant (i.e. several feet) multi-path error are found, then a new location for the ground-station antenna should be selected and tested. If only one or two isolated, brief multi-path incidents are found, then antenna location can be retained but aircraft testing should not be conducted during these periods.

Note.- The satellite-user geometry repeats over a cycle of approximately 23 hr 56 min. Thus if a ground station multi-path incident is observed one day, it is expected that a similar incident will occur 4 min earlier the following day.

These procedures are similar to those utilized by the U.S. Coast Guard in checking out a marine DGPS station installation (References 3 and 5)[8]. After establishing a ground station antenna site/configuration that satisfies the multi-path conditions criterion, the ground-station antenna should not be moved without performing another multi-path test. The ground station GPS receiver and any computer used in conjunction with the receiver may be removed and re-installed without repeating the multi-path test. The multi-path, verification test data should be saved as part of the permanent test-series data archive, and should be made available for inspection by the certificating authority.

---

8 Coast Guard DGPS ground stations employ two GPS receiver/antenna pairs. The "additional" receiver/ antenna pair (termed the integrity monitor) provide a real-time continuous check on the validity of the differential corrections generated by the "basic" receiver/antenna pair (termed the reference station). DGPS ground station architectures being investigated for the FAA Local Area Augmentation System (LAAS) program employ between 2 and 4 receiver/antenna pairs to verify the corrections sent to the aircraft. No requirement for redundant ground station equipment is recommended for DGPS-based TSPI systems used in noise certification tests.

2.2.5.2.5.3 *Carrier-Based system ground station*

To mitigate the effects of multi-path conditions on DGPS-based TSPI performance, the applicant's ground station installation should meet the following recommended specifications:

a) The ground station should employ a multi-path-limiting antenna, such as one with a choke ring or an absorbing ground plane; and

b) The ground station antenna should be mounted on a pole or tower, with unobstructed visibility of the sky. A minimum height of 3.0 m (9.8 ft) above ground level is recommended for the ground station antenna.

There is no recommended requirement for collecting data to assess multi-path errors when carrier-based processing is employed.

2.2.5.2.5.4 *Aircraft installation*

It is expected that aircraft manufacturers will select a location on each aircraft model that minimizes multi-path effects. In this regard no recommended specifications have been developed. For most smaller aircraft (e.g. 10 seats or fewer) it has been found that the roof area directly behind the windshield is most advantageous. Manufacturers of larger aircraft have found forward positions on the roof to be desirable, although some have mounted the GPS antenna on the tail structure. Selecting a location for the GPS antenna on a helicopter may be more challenging since the main rotor will momentarily obscure most areas on the airframe.

2.2.5.2.6 Other sources of DGPS error

2.2.5.2.6.1 *Correction latency*

Correction latency, also called staleness, refers to the delay between the time of validity of a differential correction at the ground station and the time that the correction is applied in the aircraft. Delays in processing at both ends of the ground-to-air data link can cause stale corrections to introduce unacceptably large errors.

A second form of latency, solution latency, refers to the delay between the time at which a GPS receiver's measurement is valid and the time when it is available at the output of the receiver. Solution delays are inherently smaller than correction delays and, in this context, are only of concern for aircraft guidance.

For a system with a real-time data link which employs code-based DGPS solutions, it is strongly recommended that ground-to-aircraft messages conform to the RTCM/SC-104 standards used by the Coast Guard DGPS system[9] These messages contain pseudo-range rates-of-change, as well as the correction at an identified time, to allow the user to correct for most of the latency-induced error. It is also preferred that the corrections be computed and transmitted at least at a 0.5 Hz rate.

2.2.5.2.6.2 *Tropospheric delay*

The troposphere is that portion of the atmosphere between the earth's surface and an altitude of approximately 32 km (20 miles). Differences in meteorological conditions between ground station and aircraft can cause dissimilar changes in the propagation times of signals from a satellite to these two locations. The effect is most pronounced for low-elevation-angle satellites. Since these changes are not common to the two locations, they are not removed by differential corrections. Such tropospheric effects can contribute up to 20 m (66 ft) of ranging error on GPS signals, which can translate into as much as 10 m to 12 m (33 ft to 39 ft) of positioning error if not modelled and corrected. In differential mode this positioning error is typically less than 2 m (6.6 ft). Approximately 90 per cent of these tropospheric propagation-related errors are due to the hydrostatic, or dry, component of tropospheric delay.

---

[9] The U.S Coast Guard DGPS system's (as well as marine systems of other nations) broadcast messages include the rate-of-change of each pseudo-range error, in addition to the pseudo-range error at a reference time. The user's receiver is required to apply an adjusted correction consisting of the broadcast pseudo-range error, plus its rate-of-change multiplied by the time elapsed between the time the adjusted correction is applied, and the validity time for the pseudo-range correction.

Experiments performed for the FAA LAAS program have found tropospheric differences to introduce DGPS errors between 0.3 m and 0.9 m (1 ft and 3 ft) when the aircraft was at 914 m (3,000 ft) altitude, but only a few centimetres when the receiver antennae were at the same altitude. To reduce the effects of tropospheric errors on DGPS-based TSPI systems used in noise certification tests, it is recommended that use of these systems be limited to the aircraft being within a lateral distance of 37 km (20 n mile) and a height of 1524 m (5,000 ft) relative to the ground station.

If desired, the hydrostatic component of the tropospheric delay can be effectively removed with the application of the tropospheric delay model (Reference 6) developed by the Radio Technical Commission for Aeronautics (RTCA) per ICAO Annex 10 Navigation Standards and Recommended Practices (SARP), along with local meteorological measurements at the ground station. The relevant portion of this model is driven by local barometric pressure and satellite geometry (i.e. elevation angle). Reference 7 provides a functional overview of the RTCA model, as well as comparisons with other tropospheric propagation delay models.

2.2.5.2.6.3 <u>Mismatched GPS receivers</u>

Experiments have shown that DGPS errors are increased when the GPS receivers at the ground station and in the aircraft are not "matched" in terms of manufacturer and model. With mismatched receivers, errors are increased moderately (e.g. 1.5 to 3 times) compared to those when the receivers are matched and when the satellites are operating normally. When a rare soft satellite-failure, or signal degradation, occurs errors of several thousand feet have been observed[10] It is required that applicant's systems have the same manufacturer/model GPS receiver on the ground and in the aircraft.

2.2.5.2.6.4 <u>Mismatched satellite ephemeris/clock data</u>

GPS satellite broadcasts include a navigation message in the form of 50 bit/s modulation superimposed on the pseudorandom codes used for ranging. Within the navigation message are data sets that describe the satellite orbit (i.e. ephemeris information) and clock. These data sets are transmitted every 30 s. The GPS Control Segment uploads multiple ephemeris and clock data sets to the satellites, typically once per day.

Note.- The Control Segment is the ground-based portion of the total GPS system. It includes the Operational Control facility in Colorado Springs, Colorado, USA where the satellite ephemeris and clock data are calculated, five worldwide sites which collect satellite broadcast signals and provide data to the Operational Control facility and three locations from which new ephemeris/clock data are uploaded to the satellites.

Satellites typically change their broadcast ephemeris and clock message every four hours. The ephemeris/clock data sets are used by a receiver to compute its own position and, in the case of a reference station, differential corrections for use by other receivers. For a DGPS system to achieve full accuracy both the ground station and aircraft receiver must use the same ephemeris and clock data sets. Internal receiver logic ensures that the ephemeris and clock data sets used by a given receiver are consistent for each satellite. However, occasionally the ground and aircraft receivers may use different ephemeris/clock data sets unless measures are taken by the user to ensure that the sets match. Mismatched ephemeris/clock data sets can occur for several reasons (e.g. a receiver is too busy performing other tasks when the data sets change, or a receiver encounters an error while decoding new data and continues to use an old data set).

The RTCM/SC-104 messages used by the Coast Guard DGPS system guard against mismatched ephemeris/clock data sets by including the Issue of Data (IOD), an eight-bit data set label broadcast by each satellite, in the broadcast messages (References 3 and 5). User receivers which conform to the RTCM/SC-104 standards will not apply differential corrections unless the IOD from the satellite and the DGPS correction message agree. The applicant

---

10 Beginning on or before October 21,1993, some differential users with mismatched ground and aircraft receivers experienced position errors of thousands of feet. The DOD's GPS Joint Program Office (JPO) attributed the cause to a "deficiency" in C/A code broadcast by satellite SVN19. It announced that the problem was corrected on January 10, 1994. Official statements are found in Notice Advisory to NAVSTAR User (NANU) 343-93294, 396-93337, and 006-94010.

should ensure that the ground station and aircraft use the same ephemeris and clock data sets during testing. One way is to purchase GPS receivers and select DGPS messages which cause this check to be performed automatically. Another way to ensure agreement between the ground and aircraft ephemeris/clock data sets is to store in a permanent file for record-keeping, at a rate of once each 30 s, the IOD used by each receiver and compare the IODs during post-test processing.

2.2.5.3 *System approval recommendations*

This section summarizes approval recommendations for DGPS-based TSPI systems proposed for use during noise certification tests.

2.2.5.3.1 Design issues

Each applicant's TSPI system design should address the issues identified in Table 2-1. The applicant's documentation (2.2.5.3.3) should address each item in the table.

Number	Issue	Major Considerations
1	Selection of processing method (real-time vs. post-test)	Need for aircraft guidance; ability to check test run quality.
2	Selection of solution method (carrier vs. code)	Accuracy (favors carrier); robustness (favors code); cost (favors code).
3	Use of geodetic or waypoint coordinates	Waypoints can simplify post-processing but not available for all receivers
4	Selection of GPS receiver and antenna	Items 1, 2, 3, and others (antenna multi-path control; data messages; solution latency; matched air/ground receivers; and IOD capability).
5	Selection of data link equipment (if real-time system)	Assigned frequency, data rate, error detection/correction, flexible interface

Table 2-1 TPSI Systems Design Development Issues

2.2.5.3.2 Data storage (logging) during noise testing

2.2.5.3.2.1 *For system with real-time data link*

For applicants employing a real-time data link, the ground-station GPS receiver should output RTCM/SC-104 Type-1 messages at a rate of 0.5 Hz or greater, which should be transmitted to, and used by the aircraft GPS receiver. The applicant's aircraft computer should collect data from the aircraft GPS receiver and generate permanent data files containing:

a) the three-dimensional aircraft position copied directly from the receiver's data port (i.e. in raw/native form) and not processed;

b) if waypoint navigation is used the waypoints (i.e. latitude, longitude, and altitude) used to define the local coordinate frame;

c) the time (e.g. UTC or GPS time), with or without a local offset, associated with each sample of position data copied directly from the receiver's data port; and

d) the data quality/validity indication associated with each sample of position data.

If waypoints are used they should be included in the header of each data file. New waypoints should not be able to overwrite existing waypoints. If new waypoints are defined then a new data file should be created.

For consistency with the noise-data collected during a certification test it is recommended that the data associated with a), c), and d) above, be saved in the GPS receiver's raw/native format at a rate greater or equal to 2 Hz, the rate associated with the noise data. However, if hardware limitations preclude following this recommendation a sampling rate of 0.5 Hz or greater is acceptable.

2.2.5.3.2.2 *For system not using real-time data link*

TSPI systems which do not use a real-time data link should save data from both the ground and aircraft GPS receivers in raw/native format in a permanent file for record-keeping. Manufacturers' proprietary formats should be used. NMEA standard messages do not support this application.

Stored data should include: time (e.g. UTC or GPS time) with or without a local offset, satellite ephemeris, pseudo-range, signal-to-noise ratio, and carrier phase. If tropospheric delay is being modelled, as described in 2.2.5.2.6.2, then local meteorological conditions should be measured and stored as well. It is recommended that applicants using dual-frequency (L1/L2) receivers also save L2 carrier phase data. Typically, post-processing of the ground-based and airborne GPS data will be performed using manufacturer supplied software. If this is not the case then any applicant developed software should be approved by the certificating authority.

2.2.5.3.3 Documentation

The applicant should prepare and submit documentation which includes:

a) *System Description*

Identifies, at a minimum, the issues in Table 2-1;

b) *Hardware Description*

Model and version number of all system components, including DGPS receivers, antennae, transceivers, and computer;

c) *Software Description*

Software functionality and capabilities, data file formats, hardware required, and operating system;

d) *System Setup and Operation*

Ground and aircraft installation of the system including antennae, operating procedures, site survey procedures, power requirements, and system limitations; and

e) *Validating of the Installation*

A method often used is to park the aircraft at a known surveyed location and to read its position from the DGPS system. From a comparison of the DGPS and surveyed positions the installation can be verified. This can be performed either at the test site or at another location, such as the aircraft home base. As a minimum this process should be performed at the start and end of each measurement program, and preferably at the beginning and end of each measurement day.

2.2.5.3.4 Accuracy verification test

The applicant should perform a one-time verification of the system accuracy, based on a minimum of six aircraft flight test runs which encompass the conditions (i.e. speed, altitude, range and manoeuvres) for which the system will be later used as a reference. The accuracy verification test should involve a comparison of the DGPS-based TSPI system's position data with those from an accepted reference, such as a laser tracker or another approved DGPS system. This test should be performed on the complete DGPS-based TSPI system developed by the applicant. It is not adequate for an applicant seeking system approval to simply cite prior approval of another applicant's system designed around the same GPS receiver.

2.2.5.3.5 Software verification

Prior to using the system during a noise-measurement program, any applicant-developed software for data logging and post processing used to obtain data listed herein should be approved by the certificating authority. The approved software should be placed under version management.

2.2.5.3.6 Ground-Station multi-path mitigation and verification

2.2.5.3.6.1 *All Systems*

The ground-station GPS receiver antenna should have a choke ring, absorbing ground plane, or other multi-path-reducing technique. The antenna should be positioned on a pole or tower at a minimum height of 10 feet above ground level.

2.2.5.3.6.2 *Code-Based systems*

Prior to each measurement program, applicants using code-based DGPS systems should perform a multi-path investigation using the ground-station receiver and antenna, as described in 2.2.5.2.5.2. The results of the investigation should be saved as part of the permanent test-series data archive, and be made available for inspection by the certificating authority.

2.2.5.3.7 Airport survey

Additional information on survey requirements may be found in 2.2.5.2.2. Prior to, and after completion of, each measurement program the applicant should use the DGPS-based TSPI system to survey the locations of:

a) if no other method of survey is used, all microphones and, if used, waypoints; or

b) if another method of survey is used, a recommended minimum of at least three points common to both methods.

Survey data should be stored as part of the measurement-program permanent archive. If two survey methods are used, the common points should be reconciled to an accuracy of 0.3 m (1 ft) and the adjustment procedure submitted to the certificating authority for approval.

2.3 ON-BOARD FLIGHT DATA ACQUISATION

2.3.1 General

It is necessary to obtain the values of a variety of flight and engine parameters during the noise measurement period in order to:

a) determine the acceptability of noise certification flight tests;

b) obtain data to adjust noise data; and

c) to synchronise flight, engine and noise data.

Typical parameters would include airspeed, climb angle, height/altitude, gross weight, flap position, landing gear position, jet engine thrust (power) setting parameters (e.g. compressor rotor speed, engine pressure ratio and exhaust gas temperature), helicopter rotor speed, engine torque and propeller rotational speed.

A number of methods for collecting this information have been employed:

a) manual recording;

b) magnetic tape recording;

c) digital recording;

d) automatic still photographic recording;

e) cine recording; and

f) video recording.

Clearly, when a large number of parameters have to be collected at relatively short time intervals, it may not be practicable to manually record the data. Thus the use of one of the automatic systems listed in b) to f) becomes more appropriate. The choice of a particular system may be influenced by a number of factors, such as the space available, cost and availability of equipment.

For systems which optically record the flight deck instruments care must be taken to avoid strong lighting contrast such as would be caused by sunlight and deep shadow, and reflections from the glass fronts of instruments which would make data unreadable. To avoid this, it may be necessary to provide additional lighting to "fill in" the deep shadow regions. To prevent reflections from the front of instruments it is recommended that light coloured equipment or clothing on the flight deck be avoided. Flight crews should be required to wear black or dark coloured clothing and gloves.

Furthermore, for systems which record the readings of dials it is important that the recording device is as near as possible directly in front of the instruments to avoid parallax errors.

2.3.2 Magnetic tape recording

Multi-channel instrumentation tape recorders designed for airborne environments are employed for continuous recording of flight and engine performance parameters. Typical recorders are compact intermediate/wide band and can take both ½-inch and 1-inch magnetic tapes with a 24 to 28 volt DC power requirements. Six tape speeds as well as both direct and FM recording are available in a tape recorder weighing about 27 kg (60 lb).

2.3.3 Automatic still photographic recording

Photographs of the flight deck instrument panel can be taken by using a hand held 35 mm single-lens reflex (SLR) camera with an 85 mm lens and high speed slide film. The indications on the instruments can be read by projecting the slides onto a screen.

2.3.4 Cine recording

Cine cameras with a one frame per second exposure rate have been used to acquire flight deck data. Care must be taken in mounting the camera to ensure that all the instruments that have to be photographed are within the field of view. Typical film cassettes containing about 2 000 frames have been used with a frame counter to allow film changes to be anticipated.

2.3.5 Video recording

Flight and engine performance parameters can be recorded with a video camera, although as with cine cameras, care must be taken to ensure that all the instruments that have to be photographed are within the field of view. The recorded information is played back using freeze-frame features to obtain individual instrument readings.

2.4 TIME SYNCHRONIZATION OF MEASURED DATA

2.4.1 General

Section 2.3.2 of Appendix 2 of the Annex specifies that there be precise time synchronization between noise measurements and airplane position. Several methods have been used, such as noting the synchronisation time on a clock mounted on the instrument panel which itself is recorded by the data acquisition system. One such system uses a ground camera which operates a radio transmission which, when received by an aircraft, lights two high-intensity light emitting diodes (LEDs) that are mounted in an analogue clock attached to the instrument panel. Other methods for acquiring and processing time-space-position information (TSPI) are described in subsequent sections.

A common time base should be used to synchronize noise, aircraft tracking, and meteorological measurements. TSPI data should be determined at half-second intervals throughout the sound-measuring period (i.e. within 10 dB of PNLTM) by an approved method that is independent from systems installed aboard, and normally used to control the airplane. During processing, measured TSPI data should be interpolated over time to the time of sound emission of each half-second acoustic data record within the 10 dB-down period. Although the simplified procedure requires adjustment of only the PNLTM record to the reference flight path, emission coordinates should be determined for each half-second record for use in background noise adjustment procedures and for determination of incidence-dependent free-field microphone and windscreen corrections.

2.4.2 TSPI equipment and software approval

Some off-the-shelf TSPI equipment may require software enhancement to accommodate the specific installation. All TSPI equipment and software should be demonstrated to, and approved by, the certificating authority to ensure the system's operational accuracy.

2.4.3 Continuous time-code recording

This method uses a time-code signal, such as IRIG B, which is a modulated, audio-frequency signal used for encoding time-base data, and developed by the Inter-Range Instrumentation Group (IRIG). In this method, the time-code signals from individual generators that have been synchronized to a common time-base are continuously recorded by both the noise data recorder(s) and by the TSPI system during measurement test runs. Synchronization of multiple generators can be performed either physically, by interconnecting via cable, or by means of radio transmission. The transmitted continuous time-code signal can be recorded directly, or used either continuously or in bursts to maintain synchronization of an independent time-code generator which is being recorded directly. This method allows for high-quality continuous time-code recording when there are intermittent reception problems.

Note 1.- Synchronization should be accomplished at the start of each measurement day and checked at the end of each measurement day to minimize the effects of generator time drift. Any such drift should be documented and accounted for in processing.

Note 2.- Global Positioning System (GPS)-based measurement systems are often used for acquisition of TSPI data. GPS receivers are capable of providing the user with precise time-base information broadcast from the GPS satellite system, in some cases eliminating the need for a separate time keeping device in the TSPI system.

Note 3.- For noise data recording or for non-GPS-based-TSPI systems, dedicated IRIG B time-code generators are available that use the GPS signal to constantly update and maintain time synchronization. Use of such a universal broadcast time-base can greatly simplify the logistics of time synchronization between measurement systems.

Note 4.- There are two available time-bases for GPS-based systems, GPS Time and Coordinated Universal Time (UTC), whose values differ by more than 10 s at any given instant. Although the GPS signal includes both time bases, not all GPS receivers give the user access to both. Therefore, the user should exercise caution in identifying which time-base is used by each instrument.

Note 5.- Many acoustical data recorders provide separate annotation channels in addition to the normal data channels. These channels are often not suitable for recording a modulated time-code signal because of limitations on dynamic range or bandwidth. In such cases a normal data channel of the recorder should be dedicated to recording the time-code signal.

Note 6.- When continuous time-code recording is used analysis of the recorded acoustic data can be initiated by routing the time-code channel output into a time-code reader and triggering the analyzer based on readout time.

2.4.4 Recording of single time marker

This method involves transmittal and recording of a radio "hack", or tone, usually used to indicate the "recorders on" or "overhead" time instant. This method typically requires a dedicated channel on both the noise and the TSPI recording systems. When such a system is used analysis can be triggered manually by an operator listening for the hack, or by a detector circuit responding to the tone. When the operator wishes to start analysis at a time other than that of the time marker, a stopwatch or delay circuit can be used to delay triggering of the analyzer. When manual triggering is employed the operator should use extreme care to perform the triggering as accurately as possible. Accuracy to within one-tenth of a second can be expected from a conscientious human operator.

2.4.5 Measurement of interval between recorder start and overhead

This method of synchronization involves use of a stopwatch or elapsed-time indicator to measure the interval between start-up of the noise data recorder and the instant that the aircraft position is overhead the centerline noise measurement point. This method can be employed successfully as long as the operator exercises care in timing, the determination of the overhead instant is performed accurately, and the start-up characteristics of the recorder (in both record and playback modes) are known and repeatable. Some recorders have variable startup times that cannot be predicted. Such recorders are not suitable for this method of synchronization.

2.4.6 Setting of internal time-stamp clock

Many digital recorders maintain a continuous internal time-of-day function by encoding time data in the recorded data stream. This method uses a digital recorder's sub-code time, synchronized to the time-base used for the TSPI data. As with the continuous time-code recording method synchronization by this method should be checked at the beginning and end of each measurement day, and any drift accounted for in processing.

Unfortunately, the time-setting function on many recorders does not provide for the necessary precision. The "second" digits cannot be made to "tick" in synchrony with an external clock. Such recorders are unsuitable for this method of synchronization.

2.4.7 Additional time-synchronization considerations

Regardless of the synchronization method used, all elements affecting time synchronization such as analyzer start-up delay, head displacement between normal and annotation data channels on analog recorders and delays in automated triggering circuits should be identified, quantified, and accounted for in analysis and processing. Whenever human response to a timing event is required errors cannot be accurately predicted, and conscientious operation is required to minimize such errors. The use of automated methods is preferred. Other methods, or variants of the listed methods, may be appropriate, but the use of all methods and instrumentation is subject to prior approval by the certificating authority.

2.5 CALCULATION OF CONFIDENCE INTERVALS

2.5.1 Introduction

The use of Noise-Power-Distance (NPD) curves requires that confidence intervals be determined by using a more general formulation than is used for a cluster of data points. For this more general case, confidence intervals may have to be calculated about a regression line for:

a) flight test data;

b) a combination of flight test and static test data; and

c) analytical results; or

d) a combination thereof.

Items b) and c) are of particular significance for noise certifications of an aircraft model range and require special care when pooling the different sources of sampling variability.

Sections 2.5.2 to 2.5.5 provide an insight into the theory of confidence interval evaluation. Application of this theory and some worked examples are provided in 2.5.6. A suggested bibliography is given in 2.5.8 for those wishing to gain a greater understanding.

2.5.2 Confidence interval for the mean of flight test data

2.5.2.1 *Confidence interval for the sample estimate of the mean of clustered measurements*

If n measurements of Effective Perceived Noise Levels (EPNLs) ($y_1, y_2, ..., y_n$) are obtained under approximately the same conditions and it can be assumed that they constitute a random sample from a normal population with true population mean, μ, and true standard deviation, σ, then the following statistics can be derived:

$\bar{y}$ = estimate of the mean = $\frac{1}{n}\left\{\sum_{i=1}^{i=n} y(i)\right\}$, and

s = estimate of the standard deviation of the mean

$$= \sqrt{\frac{\sum_{i=1}^{i=n}(y_i - \bar{y})^2}{n-1}}\ .$$

From these and the Student's t-distribution, the confidence interval *CI* for the estimate of the mean ($\bar{y}$) can be determined, as:

$$CI = \bar{y} \pm t_{\left(1-\frac{\alpha}{2},\zeta\right)} \frac{s}{\sqrt{n}},$$

where $t_{\left(1-\frac{\alpha}{2},\zeta\right)}$ denotes the $\left(1-\alpha/2\right)$ percentile of the single-sided Student's t-test with ζ degrees of freedom (for a clustered data set $\zeta = n-1$) and where α is defined such that $100(1-\alpha)$ percent is the desired confidence level for the confidence interval. In other words it denotes the probability with which the interval will contain the unknown mean, μ. For noise certification purposes, 90 per cent confidence intervals are generally desired and thus $t_{.95,\zeta}$ is used (see Table 2-4 for a listing of values of $t_{.95,\zeta}$ for different values of ζ).

2.5.2.2 *Confidence interval for mean line obtained by regression*

If n measurements of EPNL ($y_1, y_2, ..., y_n$) are obtained under significantly varying values of engine-related parameter ($x_1, x_2, ..., x_n$) respectively, then a polynomial can be fitted to the data by the method of least squares. For determining the mean EPNL, μ, the following polynomial regression model is assumed to apply:

$$\mu = B_0 + B_1 x + B_2 x^2 + ... + B_k x^k\ .$$

The estimate of the mean line through the data of the EPNL is given by:

$$y = b_0 + b_1 x + b_2 x^2 + ... + b_k x^k \ .$$

Each regression coefficient (B_i) is estimated by b_i from the sample data using the method of least squares in a process summarised as follows.

Each observation (x_i , y_i) satisfies the equations:

$$\begin{aligned} y_i &= B_0 + B_1 x_i + B_2 x_i^{\,2} + ... + B_k x_i^{\,k} + \varepsilon_i \\ &= b_0 + b_1 x_i + b_2 x_i^{\,2} + ... + b_k x_i^{\,k} + e_i \, , \end{aligned}$$

where ε_i and e_i are, respectively, the random error and residual associated with the EPNL. The random error ε_i is assumed to be a random sample from a normal population with mean zero and standard deviation σ. The residual (e_i) is the difference between the measured value and the estimate of the value using the estimates of the regression coefficients and x_i. Its root mean square value (*s*) is the sample estimate for σ. These equations are often referred to as the normal equations.

The *n* data points of measurements (x_i , y_i) are processed as follows:

Each elemental vector ($\underline{x}_i$) and its transpose ($\underline{x}'_i$) are formed such that:

$$\underline{x}_i = \begin{pmatrix} 1 & x_i & x_i^{\,2} & . & . & x_i^{\,k} \end{pmatrix}$$, a row vector, and

$$\underline{x}'_i = \begin{pmatrix} 1 \\ x_i \\ x_i^{\,2} \\ . \\ . \\ x_i^{\,k} \end{pmatrix}$$, a column vector.

A matrix $\underline{X}$ is formed from all the elemental vectors $\underline{x}_i$ for $i = 1, \ldots, n$. $\underline{X'}$ is the transpose of $\underline{X}$.

We define a matrix $\underline{A}$ such that $\underline{A} = \underline{X'}\,\underline{X}$ and a matrix $\underline{A}^{-1}$ to be the inverse of $\underline{A}$.

In addition, $\underline{y} = (y_1 \quad y_2 \quad . \quad . \quad . \quad y_n)$, and $\underline{b} = (b_0 \quad b_1 \quad . \quad . \quad . \quad b_k)$,

with $\underline{b}$ determined as the solution of the normal equations:

$\underline{y} = \underline{X}\,\underline{b}$ and $\underline{X'}\,\underline{y} = \underline{X'}\,\underline{X}\,\underline{b} = \underline{A}\,\underline{b}$,

to give $\underline{b} = \underline{A}^{-1}\,\underline{X'}\,\underline{y}$.

The 90 per cent confidence interval CI_{90} for the mean value of the EPNL estimated with the associated value of the engine-related parameter x_0 is then defined as:

$$CI_{90} = \bar{y}(x_0) \pm t_{.95,\zeta}\, s\, v(x_0),$$

where $v(x_0) = \sqrt{\underline{x}_0 \underline{A}^{-1} \underline{x}'_0}$.

Thus $CI_{90} = \bar{y}(x_0) \pm t_{.95,\zeta}\, s \sqrt{\underline{x}_0 \underline{A}^{-1} \underline{x}'_0}$,

where:

$\underline{x}_0 = \begin{pmatrix} 1 & x_0 & x_0^{\ 2} & . & . & x_0^{\ k} \end{pmatrix}$;

$\underline{x}'_0$ is the transpose of $\underline{x}_0$;

$\bar{y}(x_0)$ is the estimate of the mean value of the EPNL at the associated value of the engine related parameter;

$t_{.95,\zeta}$ is obtained for ζ degrees of freedom. For the general case of a multiple regression analysis involving K independent variables (i.e. $K+1$ coefficients) ζ is defined as $\zeta = n - K - 1$ (for the specific case of a polynomial regression analysis, for which k is the order of curve fit, we have k variables independent of the dependent variable, and so $\zeta = n - k - 1$); and

$$s = \sqrt{\frac{\sum_{i=1}^{i=n} (y_i - \bar{y}(x_i))^2}{n - K - 1}}$$, the estimate of σ, the true standard deviation.

2.5.3 <u>Confidence interval for static test derived NPD curves</u>

When static test data are used in family certifications, NPD curves are formed by the linear combination of baseline flight regressions, baseline projected static regressions, and derivative projected static regressions in the form:

$$EPNL_{DF} = EPNL_{BF} - EPNL_{BS} + EPNL_{DS},$$

or using the notation adopted above:

$$\bar{y}_{DF}(x_0) = \bar{y}_{BF}(x_0) - \bar{y}_{BS}(x_0) + \bar{y}_{DS}(x_0),$$

where:

DF denotes derivative flight;

BF denotes baseline flight;

BS denotes baseline static; and

DS denotes derivative static.

Confidence intervals for the derivative flight NPD curves are obtained by pooling the three data sets, each with their own polynomial regression. The confidence interval for the mean derived EPNL at engine-related parameter x_0, i.e. for $\mu_{DF}(x_0)$, is given by:

$$CI_{90}(x_0) = \bar{y}_{DF}(x_0) \pm t' v_{DF}(x_0)$$

where:

$$v_{DF}(x_0) = \sqrt{(s_{BF} v_{BF}(x_0))^2 + (s_{BS} v_{BS}(x_0))^2 + (s_{DS} v_{DS}(x_0))^2}$$

with s_{BF}, s_{BS}, s_{DS}, $v_{BF}(x_0)$, $v_{BS}(x_0)$, $v_{DS}(x_0)$ computed as explained in 2.5.2.2 for the respective data sets indicated by the subscripts *BF*, *BS*, and *DS*, and

$$t' = \frac{(s_{BF} v_{BF}(x_0))^2 t_{BF} + (s_{BS} v_{BS}(x_0))^2 t_{BS} + (s_{DS} v_{DS}(x_0))^2 t_{DS}}{(s_{BF} v_{BF}(x_0))^2 + (s_{BS} v_{BS}(x_0))^2 + (s_{DS} v_{DS}(x_0))^2}$$

where t_{BF}, t_{BS}, t_{DS} are the $t_{.95,\zeta}$ values each evaluated with the respective degrees of freedom ζ_{BF}, ζ_{BS}, ζ_{DS} as they arise in the corresponding regressions.

2.5.4 Confidence interval for analytically derived NPD curves

Analysis may be used to determine the effect of changes in noise source components on certificated levels. This is accomplished by analytically determining the effect of hardware change on the noise component it generates. The resultant delta (Δ) is applied to the original configuration and new noise levels are computed. The changes may occur on the baseline configuration or on subsequent derivative configurations. The confidence intervals for this case are computed using the appropriate method from 2.5.2 and 2.5.3.

If $\hat{\Delta}$ represents the analytically determined change and if it is assumed that it may deviate from the true unknown Δ by some random amount, *d* such that:

$$\hat{\Delta} = \Delta + d,$$

where d is assumed to be normally distributed with mean zero and known variance τ^2, then the confidence interval for $\mu(x_0) + \Delta$ is given by:

$$(\bar{y}(x_0) + \hat{\Delta}) \pm t' v'(x_0),$$

where $v'(x_0) = \sqrt{v(x_0)^2 + \tau^2}$ and t' is as above without change.

2.5.5 Adequacy of the Model

2.5.5.1 *Choice of engine-related parameter*

Every effort should be made to determine the most appropriate engine-related parameter *x*, which may be a combination of various simpler parameters.

2.5.5.2 ***Choice of regression model***

It is not recommended in any case that polynomials of greater complexity than a simple quadratic be used for certification purposes, unless there is a clear basis for using a higher order polynomial.

Standard texts on multiple regression should be consulted and the data available should be examined to show the adequacy of the model chosen.

2.5.6 **Worked example of the determination of 90 per cent confidence intervals from the pooling of three data sets**

2.5.6.1 ***Introduction***

This section presents an example of the derivation of the 90 per cent confidence intervals arising from the pooling of three data sets. Worked examples and guidance material are presented for the calculation of confidence intervals for a clustered data set as well as for first order (i.e. straight line) and second order (i.e. quadratic) regression curves. In addition this section also shows how the confidence interval shall be established for the pooling together of several data sets.

Consider the theoretical evaluation of the certification noise levels for an aircraft retro-fitted with silenced engines. The approach noise level for the "flight datum" aircraft was derived from a clustered data set of noise levels measured at nominally reference conditions, to which were added source noise corrections derived from a quadratic least squares curve fit through a series of data points made at different engine thrusts. In order to evaluate the noise levels for the aircraft fitted with acoustically treated engines, a further source noise curve, assumed to be a straight least squares regression line, was established from a series of measurements of the silenced aircraft. Each of the three data bases is assumed to be made up of data unique to each base.

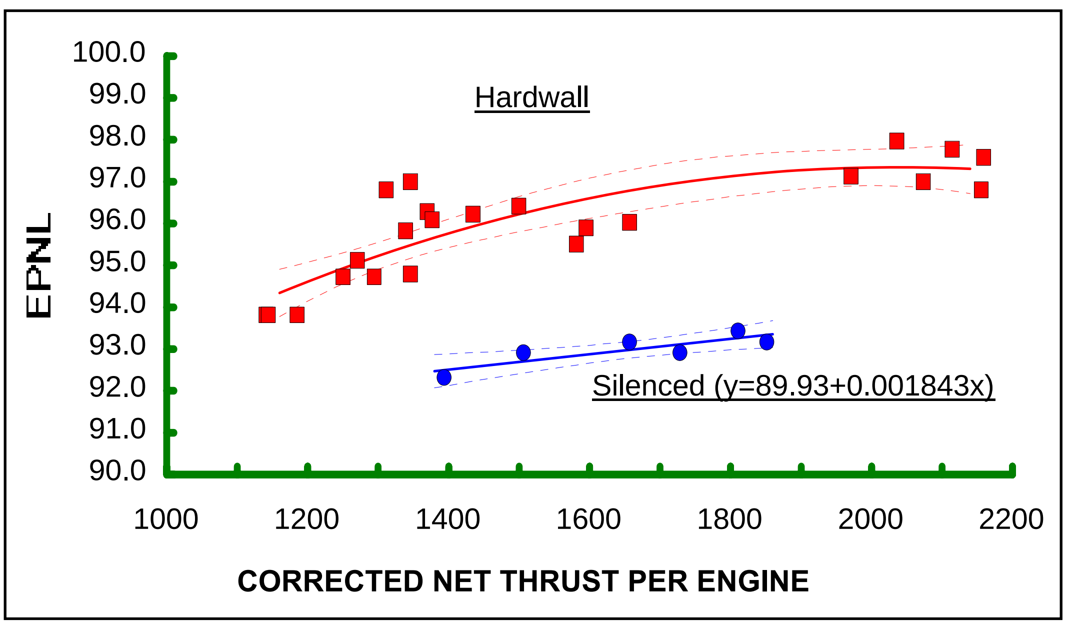


Figure 2-5 Regression curves for plots of EPNL against normalized thrust for hardwall and silenced conditions

The clustered data set consists of six EPNL levels for the nominal datum hardwall condition. These levels have been derived from measurements which have been fully corrected to the hardwall approach reference condition.

The two curves which determine the acoustic changes are the regression curves (in this example quadratic and straight line least squares fit curves) for the plots of EPNL against normalised thrust for the hardwall and silenced conditions. These are presented in Figure 2-5 where the dotted lines plotted about each line represent the boundaries of 90 per cent confidence.

Each of the two curves is made up from the full set of data points obtained for each condition during a series of back-to-back tests. The least squares fits therefore have associated with them all the uncertainties contained within each data set. It is maintained that the number of data points in each of the three sets is large enough to constitute a statistical sample.

2.5.6.2 ***Confidence interval for a clustered data set***

The confidence interval for the clustered data set is defined as follows:

Let $EPNL_i$ be the individual values of EPNL,

n = number of data points, and

t = Student's t-distribution for (n-1) degrees of freedom (i.e. the number of degrees of freedom associated with a clustered data set).

Then the Confidence Interval $CI = \overline{EPNL} \pm t\frac{s}{\sqrt{n}}$,

where s, the estimate of the standard deviation, is defined as:

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}\left(EPNL_i - \overline{EPNL}\right)^2}{n-1}}$$, and

$$\overline{EPNL} = \frac{\sum_{i=1}^{i=n} EPNL_i}{n}.$$

Let us suppose that our clustered set of EPNL values consists of the following:

Run Number	EPNL
1	95.8
2	94.8
3	95.7
4	95.1
5	95.6
6	95.3

Then the number of data points (n) = 6, the degrees of freedom ($n-1$) = 5, and the Student's t-distribution for 5 degrees of freedom = 2.015 (see Table 2-4), and so:

$$\overline{EPNL} = \frac{\sum_{i=1}^{i=n} EPNL_i}{n} = 95.38 \text{ ,}$$

$$s = \sqrt{\frac{\sum_{i=1}^{i=n}\left(EPNL_i - \overline{EPNL}\right)^2}{n-1}} = 0.3869$$,and the confidence interval (CI) can is calculated as follows:

$$CI = \overline{EPNL} \pm t\frac{s}{\sqrt{n}} = 95.38 \pm 2.015\frac{0.3869}{\sqrt{6}} = 95.38 \pm \underline{\underline{0.3183}}$$

2.5.6.3 ***Confidence interval for a first order regression curve***

Let us suppose that the regression curve for one of the source noise data sets, the silenced case, can best be represented by a least squares straight line fit (i.e. a first order polynomial).

The equation for this regression line is of the general form:

$$Y = a + bX$$

where Y represents the dependent variable $EPNL$, and X represents the independent variable, in this case normalised thrust F_N/δ .

Although for higher order polynomial least squares curves a regression line's coefficients (i.e. the solutions to the "normal equations") are best established through computer matrix solutions, the two coefficients for a straight line fit, a and b, can be determined from the following two simple formulae for the measured values of X and Y, X_i and Δ_i:

$$a = \frac{\sum_{i=1}^{i=n} Y_i - b\sum_{i=1}^{i=n} X_i}{n}$$; and

$$b = \frac{Covariance}{Variance} = \frac{S_{xy}{}^2}{S_x{}^2}$$, where:

$$S_{xy}{}^2 = \frac{\sum_{i=1}^{i=n} X_i Y_i}{n} - \frac{\sum_{i=1}^{i=n} X_i \sum_{i=1}^{i=n} Y_i}{n^2}$$, and

$$S_x{}^2 = \frac{\sum_{i=1}^{i=n} X_i{}^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n}\right)^2 .$$

The 90 per cent confidence interval about this regression line for $X = x_0$ is then defined by:

$$CI_{90} = \overline{Y} \pm ts\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'}$$

where:

t = Student's t-distribution for 90 per cent confidence corresponding to (*n*-*k*-1) degrees of freedom, where *k* is the order of the polynomial regression line and *n* is the number of data points;

$$\underline{x_0} = \begin{pmatrix}1 & x_0\end{pmatrix};$$

$$\underline{x_0}' = \begin{pmatrix}1 \\ x_0\end{pmatrix};$$

$\underline{A}^{-1}$ is the inverse of $\underline{A}$ where $\underline{A} = \underline{X'X}$, with $\underline{X}$ and X' defined as in 2.5.2.2 from the elemental vectors formed from the measured values of the independent variable X_i; and

$s = \sqrt{\dfrac{\sum_{i=1}^{i=n}(\Delta Y)_i^2}{n-k-1}}$ where $(\Delta Y)_i$ = the difference between the measured value of Y_i at its associated value of X_i, and the value of Y derived from the least squares fit straight line for $X = X_i$, and *n* and k are defined as the number of data points and the order of the polynomial regression line, respectively.

Let us suppose that our data set consists of the following set of six EPNL values, together with their associated values of engine-related parameter (see Table 2-2. Note that it would be usual to have more than six data points making up a source noise curve but in order to limit the size of the matrices in this example the number of data points has been restricted.

Run Number	F_N/δ	EPNL
1	1395	92.3
2	1505	92.9
3	1655	93.2
4	1730	92.9
5	1810	93.4
6	1850	93.2

Table 2-2 Values of sample data set

By plotting this data (see Figure 2-5) it can be seen by examination that a linear relationship between EPNL (the dependent variable *Y*) and F_N/δ (the independent variable *X*) is suggested with the following general form:

$$Y = a + bX.$$

The coefficients *a* and *b* of the linear equation are defined as above and may be calculated as follows:

X	Y	XY	X^2
1395	92.3	128 759	1 946 025
1505	92.9	139 815	2 265 025
1655	93.2	154 246	2 739 025
1730	92.9	160 717	2 992 900
1810	93.4	169 054	3 276 100
1850	93.2	172 420	3 422 500
$\sum X$	$\sum Y$	$\sum XY$	$\sum X^2$
9945	557.9	925 010	16 641 575

$$a = \frac{\sum_{i-1}^{i=n} Y_i - b\sum_{i=1}^{i=n} X_i}{n} = \frac{557.9 - (0.001843)(9945)}{6} = \underline{\underline{89.93}} \text{, and}$$

$$b = \frac{Covariance}{Variance} = \frac{S_{xy}{}^2}{S_x{}^2} \text{, where:}$$

$$S_{xy}{}^2 = \frac{\sum_{i=1}^{i=n} X_i Y_i}{n} - \frac{\sum_{i=1}^{i=n} X_i \sum_{i=1}^{i=n} Y_i}{n^2}$$

$$= \frac{925010}{6} - \frac{(9945)(557.9)}{36} = 48.46 \text{ ; and}$$

$$S_x{}^2 = \frac{\sum_{i=1}^{i=n} X_i{}^2}{n} - \left(\frac{\sum_{i=1}^{i=n} X_i}{n} \right)^2$$

$$= \frac{16641575}{6} - \left(\frac{9945}{6}\right)^2 = 26289.6 \text{, to give:}$$

$$b = \frac{48.46}{26289.6} = \underline{\underline{0.001843}} \text{ .}$$

The 90 per cent confidence interval about this regression line is defined as:

$CI_{90} = \overline{Y} \pm ts\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'}$,and is calculated as follows.

From the single set of measured independent variables tabulated in Table 2-2 let us form the matrix, $\underline{X}$, from the elemental row vectors such that:

$$\underline{X} = \begin{pmatrix} 1 & 1395 \\ 1 & 1505 \\ 1 & 1655 \\ 1 & 1730 \\ 1 & 1810 \\ 1 & 1850 \end{pmatrix}$$, and $\underline{X}'$, the transpose of $\underline{X}$, where

$$\underline{X}' = \begin{pmatrix} 1 & 1 & 1 & 1 & 1 & 1 \\ 1395 & 1505 & 1655 & 1730 & 1810 & 1850 \end{pmatrix}.$$

We now form the matrix $\underline{A}$, defined such that $\underline{A} = \underline{X}'\underline{X}$, and so:

$$\underline{A} = \begin{pmatrix} 6 & 9945 \\ 9945 & 16641575 \end{pmatrix}$$, and its inverse $\underline{A}^{-1}$ such that:

$$\underline{A}^{-1} = \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\text{E}-6 \end{pmatrix}.$$

Note.- The manipulation of matrices (i.e. their multiplication and inversion) is best performed by computers via standard routines. Such routines are possible using standard functions contained within many commonly used spreadsheets.

To find the 90 per cent confidence interval about the regression line for a value of F_N/δ (i.e. x_0) of 1600 we form the row vector ($\underline{x_0}$) and its transpose ($\underline{x_0}'$) a column vector such that:

$$\underline{x_0} = \begin{pmatrix} 1 & 1600 \end{pmatrix}$$, and

$$\underline{x_0}' = \begin{pmatrix} 1 \\ 1600 \end{pmatrix}.$$

From our calculation of $\underline{A}^{-1}$ we have:

$$\underline{x_0}\underline{A}^{-1} = \begin{pmatrix} 1 & 1600 \end{pmatrix} \begin{pmatrix} 17.5836 & -0.01051 \\ -0.01051 & 6.3396\text{E}-6 \end{pmatrix}$$

$$= \begin{pmatrix} 0.7709 & -3.6453\text{E}-4 \end{pmatrix},$$

and so:

$$\underline{x_0}\underline{A}^{-1}\underline{x_0}' = \begin{pmatrix} 0.7709 & -3.6453\text{E}-4 \end{pmatrix} \begin{pmatrix} 1 \\ 1600 \end{pmatrix} = 0.1876.$$

Our equation for confidence interval also requires that we evaluate the value of standard deviation for the measured data set. From Table 2-2 and our regression equation for the least squares best fit straight line, from which we calculate the predicted value of EPNL at each of the six measured values of FN/δ, we proceed as follows:

Run Number	F_N/δ	EPNL (Measured)
1	1395	92.3
2	1505	92.9
3	1655	93.2
4	1730	92.9
5	1810	93.4
6	1850	93.2

Run Number	EPNL (Predicted)	$(\Delta\, EPNL)^2$
1	92.50	0.03979
2	92.70	0.03911
3	92.98	0.04896
4	93.12	0.04708
5	93.26	0.01838
6	93.34	0.01909

$$s = \sqrt{\frac{\sum_{i=1}^{i=n} (\Delta\, E\text{PNL})_i^2}{n-k-1}} = \sqrt{\frac{0.21241}{6-1-1}} = 0.2304$$

for $n = 6$ and $k = 1$.

Taking the value of Student's t from Table 2-4 for $(n-k-1)$ degrees of freedom (i.e. 4) to be 2.132, we have the confidence interval about the regression line at $F_N/\delta = 1600$ defined as follows:

$$CI_{90} = \overline{EPNL} + ts\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'}$$

$$= 92.88 \pm (2.132)(0.2304)\sqrt{0.1876}$$

$$= 92.88 \pm 0.2128.$$

In order to establish the lines of 90 per cent confidence intervals about a regression line the values of CI_{90} for a range of values of independent variable(s) should be calculated, through which a line can be drawn. These lines are shown as the dotted lines on Figure 2-5

2.5.6.4 ***Confidence interval for a second order regression curve***

The confidence intervals for a second order regression curve are derived in a similar manner to those for a straight line detailed in 2.5.6.3. A detailed example of their calculation is not discussed here. However the following points should be borne in mind.

The coefficients of the least squares regression quadratic line are best determined via computer matrix solutions. Regression analysis functions are a common feature of many proprietary software packages.

The matrices $\underline{x_0}, \underline{x_0}', \underline{X}$ and $\underline{X}'$ formed during the computation of the confidence interval according to the formula:

$$CI_{90} = \overline{Y} \pm t\, s\sqrt{\underline{x_0}\,\underline{A}^{-1}\,\underline{x_0}'}\ ,$$

are formed from 1 x 3 and 3 x 1 row and column vectors respectively, made up from the values of independent variable X according to the following general form:

$$\underline{x} = \begin{pmatrix} 1 & x & x^2 \end{pmatrix} \text{ and } \underline{x}' = \begin{pmatrix} 1 \\ x \\ x^2 \end{pmatrix}.$$

The number of degrees of freedom associated with a multiple regression analysis involving K variables independent of the dependent variable (i.e. with $(K+1)$ coefficients, including the constant term) is defined as $(n-K-1)$. For a second order regression curve we have two independent variables and so the number of degrees of freedom is $(n-3)$.

2.5.6.5 ***Confidence interval for the pooled data set***

The confidence interval associated with the pooling of three data sets is defined as follows:

$$CI = \overline{Y} \pm T\sqrt{\sum_{i=1}^{i=3} Z_i^{\,2}}\ ,$$

where $Z_i = \dfrac{CI_i}{t_i}$,

with CI_i = confidence interval for the i'th data set,
t_i = value of Student's t for the i'th data set, and

$$T = \frac{\sum_{i=1}^{i=3} Z_i^{\,2} t_i}{\sum_{i=1}^{i=3} Z_i^{\,2}}.$$

The different stages in the calculation of the confidence interval at our reference thrust of $F_N/\delta = 1600$ for the pooling of our three data sets is summarised in Table 2-3.

2.5.7 Student's T-distribution (for 90 per cent confidence) for various degrees of freedom

The values in the Student's t-distribution to give a probability of 0.95 that the population mean value (μ) is such that:

$$\mu \leq \overline{y} + t_{.95,\zeta} \frac{s}{\sqrt{n}} ,$$

and thus a probability of 90 per cent that

$$\overline{y} - t_{.95,\zeta} \frac{s}{\sqrt{n}} \leq \mu \leq \overline{y} + t_{.95,\zeta} \frac{s}{\sqrt{n}} ,$$

are tabulated in Table 2-4.

<table>
<tr><th>Description</th><th>Function</th><th>Datum</th><th>Hardwall</th><th>Silenced</th></tr>
<tr><td>Reference Thrust</td><td>F_N/δ</td><td></td><td>1600</td><td>1600</td></tr>
<tr><td>90% Confidence Interval about the mean</td><td>CI_{90}</td><td>0.3183</td><td>0.4817</td><td>0.2128</td></tr>
<tr><td>Number of data points</td><td>n</td><td>6</td><td>23</td><td>6</td></tr>
<tr><td>Degree of curve fit</td><td>k</td><td>0</td><td>2</td><td>1</td></tr>
<tr><td>Number of independent variables</td><td>K</td><td>0</td><td>2</td><td>1</td></tr>
<tr><td>Number of degrees of freedom</td><td>$n-K-1$</td><td>5</td><td>20</td><td>4</td></tr>
<tr><td>Student's t</td><td>t</td><td>2.015</td><td>1.725</td><td>2.132</td></tr>
<tr><td>Z</td><td>CI_{90}/t</td><td>0.1580</td><td>0.2792</td><td>0.09981</td></tr>
<tr><td>Z^2</td><td>$\left(CI_{90}/t\right)^2$</td><td>2.4953E-2</td><td>7.7979E-2</td><td>9.9625E-3</td></tr>
<tr><td>$Z^2 t$</td><td>$\left(CI_{90}/t\right)^2 t$</td><td>5.0280E-2</td><td>0.1345</td><td>2.1240E-2</td></tr>
<tr><td>$\sum Z^2$</td><td></td><td colspan="3">0.1129</td></tr>
<tr><td>$\sum\left(Z^2 t\right)$</td><td></td><td colspan="3">0.2060</td></tr>
<tr><td>T</td><td>$\sum\left(Z^2 t\right)/\sum Z^2$</td><td colspan="3">1.8248</td></tr>
<tr><td>$\sqrt{\sum Z^2}$</td><td></td><td colspan="3">0.3360</td></tr>
<tr><td>CI</td><td>$T\sqrt{\sum Z^2}$</td><td colspan="3"><u>0.6131</u></td></tr>
</table>

Table 2-3 Example of confidence interval calculation

Degrees of Freedom (ζ)	$t_{.95,\zeta}$
1	6.314
2	2.920
3	2.353
4	2.132
5	2.015
6	1.943
7	1.895
8	1.860
9	1.833
10	1.812
12	1.782
14	1.761
16	1.746
18	1.734
20	1.725
24	1.711
30	1.697
60	1.671
>60	1.645

Table 2-4 Student's t-distribution (for 90 per cent confidence) for various degrees of freedom

2.5.8 Bibliography

1. Cochran, W.G. "Approximate Significance Levels of the Behrens-Fisher Test." *Biometrics* 10 (1964): 191-195.
2. Kendal, M.G. and A Stuart,. *The Advanced Theory of Statistics*, Volumes 1 and 2, 3. New York: Hafner, 1971.
3. Kendall, M.G and G. U. Yule. *An Introduction to the Theory of Statistics*, 14th ed., New York, Griffin, 1950.
4. Rose, D.M. and F.W. Scholz. *Statistical Analysis of Cumulative Shipper-Receiver Data,* U. S Nuclear Regulatory Commission, Division of Facility Operations, Office of Nuclear Regulatory Research, Washington, D.C. 1983. NUREG/CR-2819. NRC FIN B1076.
5. Snedecor, G.W. and W. G. Cochran. *Statistical Methods,* 6th ed., Arnes, Iowa: The Iowa State University Press, 1968.
6. Walpole, R.E. and R. H. Myers. *Probability and Statistics for Engineers and Scientists.* New York: MacMillan, 1972.
7. Wonnacott, T.H. and R. J. Wonnacott. *Introductory Statistics,* 5th ed N. p.: John Wiley &Sons, 1990.

2.6 ADJUSTMENT OF AIRCRAFT NOISE LEVELS FOR THE EFFECTS OF BACKGROUND NOISE

2.6.1 Introduction

The following information is provided as guidance material on procedures for adjusting measured aircraft noise levels for the effects of background noise.

The presence of background noise during aircraft noise certification tests can influence measured aircraft sound levels, and in some cases, obscure portions of the spectral time history used to obtain Effective Perceived Noise Level (EPNL) values. Adjustment procedures should include the following components:

a) testing to determine which portions of the spectral time history, if any, are obscured;

b) adjustment of unobscured levels to determine the aircraft sound levels that would have been measured in the absence of background noise; and

c) replacement or reconstruction of obscured levels by frequency extrapolation, time extrapolation or by other means.

A list of definitions for terms used in this appendix is provided in 2.6.2. Although some of the terms have generally accepted meanings, the specific meanings as defined apply herein.

A detailed, step-by-step procedure is presented in 2.6.3 including equations and descriptions of time and frequency extrapolation methods (see 2.6.3.2.10). Other procedures may be used provided that they have been approved by the certificating authority.

General considerations which apply to any background noise adjustment procedure are listed in 2.6.4, including requirements and limitations (see 2.6.4.1) and other special considerations (see 2.6.4.2 through 2.6.4.4)

2.6.2 Definitions

For purposes of 2.6 the following definitions apply:

Adjusted level. A valid one-third-octave band level, which has been adjusted for measurement conditions, including:

a) the energy contribution of pre-detection noise; and

b) frequency-dependent adjustments such as system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss.

Ambient noise. The acoustical noise from sources other than the test aircraft present at the microphone site during aircraft noise measurements. Ambient noise is one component of background noise.

Background noise. The combined noise present in a measurement system from sources other than the test aircraft, which can influence or obscure the aircraft noise levels being measured. Typical elements of background noise include, but are not limited to, ambient noise from sources around the microphone site, thermal electrical noise generated by components in the measurement system, magnetic flux noise (“tape hiss”) from analog tape recorders and digitization noise caused by quantization error in digital converters. Some elements of background noise, such as digitization noise, can obscure the aircraft noise signal, while others, such as ambient noise, can also contribute energy to the measured aircraft noise signal.

Energy-subtraction. Subtraction of one sound pressure level from another, on an energy basis, in the form of the following:

$$10\log_{10}\left[10^{(L_A/10)} - 10^{(L_B/10)}\right],$$

where L_A and L_B are two sound pressure levels in decibels, with L_B being the value subtracted from L_A.

Frequency extrapolation. A method for reconstruction of high frequency masked data, based on unmasked data in a lower-frequency one-third-octave band from the same spectrum.

High frequency bands. The twelve bands from 800 Hz through 10 kHz inclusive (also see “low frequency bands”).

LGB (last good band). In the adjustment methodology presented in 2.6.3, for any aircraft one-third band spectrum, the LGB is the highest-frequency unmasked band within the range of 630 Hz to 10 kHz inclusive, below which there are no masked high frequency bands.

Low frequency bands. The twelve bands from 50 Hz through 630 Hz inclusive (also see “high frequency bands”).

Masked band. Within a single spectrum, any one-third-octave band containing a masked level.

Masked level. Any one-third-octave band level which is less than or equal to the masking criterion for that band. When a level is identified as being masked, the actual level of aircraft noise in that band has been obscured by background noise and cannot be determined. Masked levels can be reconstructed using frequency extrapolation, time extrapolation or other methods.

Masking criteria. The spectrum of one-third-octave band levels below which measured aircraft sound pressure levels are considered to be masked or obscured by background noise. Masking criteria levels are defined as the greater of:

a) pre-detection noise +3 dB; or

b) post-detection noise +1 dB.

Post-detection noise. The minimum levels below which measured noise levels are not considered valid. Usually determined by the baseline of an analysis "window", or by the amplitude non-linearity characteristics of components in the measurement and analysis system. Post-detection noise levels are non-additive (i.e. they do not contribute energy to measured aircraft noise levels).

Pre-detection noise. Any noise which can contribute energy to the measured levels of sound produced by the aircraft, including ambient noise present at the microphone site and active instrumentation noise present in the measurement, record/playback and analysis systems.

Reconstructed level. A level, calculated by frequency extrapolation, time extrapolation, or by other means, which replaces the measured value for a masked band.

Sound attenuation coefficient. The reduction in level of sound within a one-third octave band, in dB per 100 meters, due to the effects of atmospheric absorption of sound.

Time extrapolation. A method for reconstruction of high frequency masked data, based on unmasked data in the same one-third-octave band, from a different spectrum in the time-history.

Valid or unmasked band. Within a single spectrum, any one-third-octave band containing a valid level.

Valid or unmasked level. Any one-third-octave band level which exceeds the masking criterion for that band.

2.6.3 Background noise adjustment procedure

2.6.3.1 *Assumptions*

a) A typical aircraft spectrum measured on the ground contains one-third-octave band levels which decrease in amplitude with increasing frequency. This characteristic high frequency roll-off is due primarily to the effects of atmospheric absorption;

d) A typical electronic instrumentation floor spectrum contains one-third-octave band levels which increase in amplitude with increasing frequency;

e) Due to the assumptions cited in a) and b), as the observed frequency is increased within a one-third-octave band aircraft spectrum, and once a band becomes masked, all subsequent higher-frequency bands will also be masked. This allows the implementation of a "Last Good Band" (LGB) label to identify the frequency band above which the bands in a spectrum are masked;

f) If, on occasion, a valid level occurs in a band with higher centre frequency than the LGB, its presence will most likely be due to small variations in the pre-detection levels and/or due to levels of the measured aircraft one-third-octave band spectrum being close to the levels of the background noise in general, so its energy contribution will not be significant. Note that this assumption is only valid in the absence of significant aircraft-generated tones in the region of masking. Therefore, the possibility of a level being valid in a band with higher centre frequency than the LGB may be ignored. Applicants who prefer to implement algorithms for identifying and handling such situations may do so, but no procedure may be used without prior approval from the certificating authority.

2.6.3.2 *Step-by step description*

2.6.3.2.1 Determination of pre-detection noise

A time-averaged one-third-octave band spectrum of pre-detection noise levels for each test run, or group of runs occurring during a short time period, should be obtained by recording and analyzing ambient noise over a representative period of time (30 s or more). Care should be taken to ensure that this "ambient" noise sample reasonably represents that which is present during measured aircraft runs. In recording ambient noise, all gain stages and attenuators should be set as they would be during the aircraft runs in order to ensure that the instrumentation noise is also representative. If multiple gain settings are required for aircraft noise measurements, a separate ambient sample should be recorded at each of the settings used.

2.6.3.2.2 Determination of post-detection noise

A one-third-octave band spectrum of post-detection noise levels should be determined as a result of testing, or from manufacturer's specifications, for each measurement/analysis configuration used, including different gain and/or sensitivity settings. These minimum valid levels may be determined on the basis of display limitations (e.g. blanking of the displayed indication when levels fall below a certain value), amplitude non-linearity, or other non-additive limitations. In cases where more than one component or stage of the measurement/analysis system imposes a set of minimum valid levels, the most restrictive in each one-third-octave band should be used.

2.6.3.2.3 Testing of pre-detection noise versus post-detection noise

The validity of pre-detection noise levels must be established before these levels can be used to adjust valid aircraft noise levels. Any pre-detection noise level which is equal to or less than the post-detection noise level in a particular one-third-octave band should be identified as invalid, and therefore should not be used in the adjustment procedure.

2.6.3.2.4 Determination of masking criteria

Once the pre-detection noise and post-detection noise spectra are established, the masking criteria can be identified. For each one-third-octave band, compare the valid pre-detection noise level +3 dB with the post-detection noise level +1 dB. The highest of these levels is used as the masking criterion for that band. If there is no valid pre-detection noise level for a particular one-third-octave band, then the post-detection noise level +1 dB is used as the masking criterion for that band. The 3 dB window above pre-detection levels allows for the doubling of energy which could occur if an aircraft noise level were equal to the pre-detection level. The 1 dB window above the post-detection levels allows for a reasonable amount of error in the determination of those levels.

2.6.3.2.5 Identification of masked levels

Each spectrum in the aircraft noise time-history can be evaluated for masking by comparing the one-third-octave band levels against the masking criteria levels. Whenever the aircraft level in a particular band is less than or equal to the associated masking criterion, that aircraft level is considered masked. A record must be kept of which bands in each spectrum are masked.

2.6.3.2.6 Determination of Last Good Band

For each half second spectral record, determine the highest frequency unmasked one-third-octave band ("Last Good Band" or "LGB") by starting at the 630 Hz band and incrementing the band number (i.e. increasing frequency) until a masked band is found. At that point, set LGB for that spectral record equal to the band below the masked band. The lowest frequency band that can be identified as LGB is the 630 Hz band. In other words, if both the 630 Hz band and the 800 Hz band are masked, no reconstruction of masked levels may be performed for that spectrum, and the thirteen bands between 630 Hz and 10 kHz inclusive should be left as-is and identified as masked. According to the masking limits specified in 2.6.4.2a such a spectrum is not valid for calculation of EPNL.

2.6.3.2.7 Adjustment of valid levels for background noise

In each half-second spectrum, for each valid band up to and including LGB, perform an energy-subtraction of the valid pre-detection level from the valid measured level in the aircraft noise time-history using:

$$10\log_{10}\left[10^{(L_{AIRCRAFT}/10)} - 10^{(L_{PRE-DETECTION}/10)}\right]$$

Energy-subtraction should be performed on all valid one-third-octave band noise levels. For any one-third-octave band where there is no valid pre-detection noise level, no energy-subtraction may be performed (i.e. this adjustment cannot be applied when either the measured aircraft noise time-history level or the pre-detection noise level is masked).

2.6.3.2.8 Adjustment of valid levels for measurement conditions

Before any reconstruction can be done for masked levels, valid levels which have been adjusted for the presence of pre-detection noise must also then be adjusted for frequency-dependent adjustments such as system frequency response, microphone pressure response and free-field response, and windscreen incidence-dependent insertion loss. These adjustments cannot be applied to masked levels.

2.6.3.2.9 Reconstruction of low frequency masked bands

In cases where a single masked low frequency one-third-octave band occurs between two adjacent valid bands, the masked level can be retained, or the arithmetic average of the adjusted levels of the adjacent valid bands may be used in place of the masked level. If the average is used, the level should be categorized as reconstructed. However, if masked low frequency bands are found adjacent to other masked low frequency bands, these masked levels should be retained and remain categorized as masked. The procedure presented in this 2.6.3 does not provide for any other form of reconstruction for masked low frequency bands.

2.6.3.2.10 Reconstruction of levels for masked high frequency bands

Frequency extrapolation and time extrapolation are the methods used to reconstruct masked one-third-octave band levels for bands at frequencies higher than LGB for each spectral record. One-third-octave band sound attenuation coefficients (either in dB per 100 m, or in dB per 1000 ft) must be determined before such reconstruction of masked band levels can be performed. Note that noise emission coordinates must also be calculated for each record before reconstruction is performed since the procedure is dependent on propagation distance.

2.6.3.2.10.1 *Frequency extrapolation method*

For a spectrum where the LGB is located at or above the 2 kHz one-third-octave band, the frequency extrapolation method is used. This method reconstructs masked high frequency bands starting with the level associated with LGB in the same spectrum. The levels for all bands at higher frequencies than LGB must be reconstructed using this method. Any frequency-extrapolated levels should be categorized as reconstructed. Reconstruct the level for the masked bands using the following equation:

$$L_{x_{i,k}} = L_{j,k} + \alpha_j \frac{SR_k}{100} - \alpha_{j_{REF}} \frac{60}{100} + 20\log_{10}\frac{SR_k}{60} + \alpha_{i_{REF}} \frac{60}{100} - \alpha_i \frac{SR_k}{100} + 20\log_{10}\frac{60}{SR_k}$$

which can be reduced to:

$$L_{x_{i,k}} = L_{j,k} + \left[\alpha_j - \alpha_i\right]\frac{SR_k}{100} + \left[\alpha_{i_{REF}} - \alpha_{j_{REF}}\right]\frac{60}{100},$$

where:

i is the masked band to be extrapolated;

k is the record of interest;

j is the Last Good Band (LGB) in record k;

$Lx_{i,k}$ is the frequency-extrapolated level in dB for masked band i and spectral record k;

$L_{j,k}$ is the level for LGB in record k after all test-day adjustments have been applied, including pre-detection noise energy-subtraction, system and microphone adjustments, etc.;

α_j is the test-day sound attenuation coefficient (dB per 100 m) for LGB;

α_i is the test-day sound attenuation coefficient (dB per 100 m) for band *i*;

α_{jREF} is the reference (25°C (77°F), 70 per cent RH) sound attenuation coefficient (dB per 100 m) for LGB;

α_{iREF} is the reference (25°C (77°F), 70 per cent RH) sound attenuation coefficient (dB per 100 m) for masked band *i*; and

SR_k is the slant range or acoustic propagation distance in metres at the time of noise emission for spectral record *k*, between the aircraft and the microphone.

This procedure is based on the assumption that the aircraft spectrum is "flat" (i.e. all high frequency band levels are equal) at a distance of 60 m (197 ft) under reference conditions (25°C (77°F), 70 per cent RH). The process can be conceptualized by means of the following steps:

a) The level for band *j,* the highest frequency unmasked band in spectral record *k*, which has already been adjusted for measurement conditions, is adjusted for test-day propagation effects to obtain the source level and then adjusted using reference propagation effects to the 60 m (197 ft) distance from the source;

b) This level is then assigned as the level for all high frequency masked bands (i.e. band i, band i+1 etc.) at a distance of 60 m (197 ft);

c) A new source level is determined for each masked high frequency band by removing the associated reference-day propagation effects; and

d) The extrapolated level that would have been measured on the ground, in the absence of background noise, is determined for each masked high frequency band by adding the test-day propagation effects to each of the source levels determined in c) above.

2.6.3.2.10.2 <u>*Time extrapolation method*</u>

For a spectrum where LGB occurs at or between the 630 Hz one-third-octave band and the 1.6 kHz band, use the time extrapolation method. This method reconstructs a masked band in a spectrum from the closest spectral record (i.e. closest in time) for which that band is valid. The levels for all one-third-octave bands with frequencies greater than that of LGB must be reconstructed using this time extrapolation method. Any time-extrapolated levels should be categorized as reconstructed. Reconstruct the levels for the masked bands by using the following equation:

$$Lx_{i,k} = L_{i,m} + \alpha_i\left[\frac{SR_m}{100} - \frac{SR_k}{100}\right] + 20\log_{10}\left[\frac{SR_m}{SR_k}\right]$$

where:

$Lx_{i,k}$ *is* the time-extrapolated level in dB for masked band *i* and spectral record *k* ;

$L_{i,m}$ *is* the adjusted level in dB for band *i* in spectral record m, which is the nearest record in time to record k in which band i contains a valid level;

SR_m *is* the slant range or acoustic propagation distance in metres at the time of noise emission for spectral record *m*, between the aircraft and the microphone;

SR_k is the slant range or acoustic propagation distance in metres at the time of noise emission for spectral record *k*, between the aircraft and the microphone; and

α_i is the test-day sound attenuation coefficient (dB per 100 m) for band *i*.

This procedure is based on the assumption that the aircraft spectrum is omni-directional during the aircraft pass-by.

2.6.3.2.11 Handling of spectra after reconstruction of masked bands

After reconstruction of masked data has been performed, the background noise adjustment procedure is complete. The adjusted as-measured data set, comprised of adjusted levels, reconstructed levels, and possibly some masked levels, is next used to obtain the test-day PNLT time-history described in 4.3 of Appendix 2 of the Annex,. The identification of masked data should be kept accessible for use during the tone correction procedure, since any tone correction which results from the adjustment for background noise may be eliminated from the process of identifying the maximum tone within a spectrum. When this background noise adjustment procedure is used, the band identified as LGB should be treated as the last band of the tone correction calculation in the manner prescribed for the 10 kHz band in 4.3.1 of Appendix 2 of the Annex, including the calculation of a new slope for band LGB+1 that equals the slope at LGB (i.e. $s'(LGB+1,k) = s'(LGB,k)$, in Step 5 of the tone correction procedure).

2.6.4 General considerations

2.6.4.1 ***Limitations and requirements for any background noise adjustment procedure.***

Any method of adjusting for the effects of background noise must be approved by the certificating authority before it is used. The adjustment procedure presented in 2.6.3.2 includes applicable limitations and requirements. Those limitations and requirements which apply to all methodologies are described as follows.

The applicant must be able to demonstrate by means of narrow-band analysis or other methods that no significant aircraft-generated tones occur in the masked one-third-octave bands during the EPNL duration.

Neither frequency-dependent adjustments nor energy-subtraction of pre-detection levels can be applied to masked data.

When consecutive one-third-octave bands in the range of 2.5 kHz to 10 kHz inclusive are masked, and when no consecutive bands are masked in the region of 800 Hz to 2 kHz inclusive, frequency extrapolation, as described in 2.6.3.2.10.1, must be performed on all consecutive masked bands with nominal frequencies greater than 2 kHz.

When consecutive one-third-octave bands in the range of 800 Hz to 2 kHz inclusive are masked, time extrapolation, as described in 2.6.3.2.10.2, must be performed on all consecutive, masked bands with nominal frequencies greater than 630 Hz.

In cases where a single masked one-third-octave band occurs between two adjacent valid bands, the levels of the adjacent adjusted bands may be arithmetically averaged, and the averaged level used in place of the masked level. If the masked level is retained it must be included when counting the masked levels in the procedure described in 2.6.4.2.

2.6.4.2 ***Rejection of spectra due to masking.***

A spectrum becomes invalid if the following conditions prevail:

a) if, after any reconstruction of masked bands, more than four one-third-octave bands retain masked values;

b) for records within one second of the record associated with the PNLTmax spectrum (i.e. five half-second data records) then:

   – if more than four high frequency bands require reconstruction; or

   – if the LGB is located at or below the 3150 Hz one-third-octave band when the example background noise adjustment procedure presented in 2.6.3.2 is used.

Note.- If an invalid spectrum occurs within the 10 dB-down period, the aircraft test run is invalid, and cannot be used for aircraft noise certification purposes.

2.6.4.3 ***Special tone correction considerations due to masking.***

When the maximum tone correction for a one-third-octave band spectrum occurs at a masked or reconstructed band, the tone correction for that spectrum cannot simply be set to zero. The maximum tone correction for the spectrum must be computed, taking masked or reconstructed levels into consideration. Any tone correction resulting from the adjustment for background noise may be eliminated by either one of the following two methods, as appropriate:

a) When the example background noise adjustment procedure presented in 2.6.3.2 is used, or specifically, when all of the high frequency bands in a spectrum are masked for frequencies beyond a certain band (i.e. "LGB") the band labelled as LGB should be treated as the last band of the tone correction calculation, in the manner prescribed for the 10 kHz band (band number 24) in 4.3.1 of Appendix 2 of the Annex, including calculation of a new slope for the band above LGB that equals the slope of the band at LGB (i.e. $s'(LGB+1,k) = s'(LGB,k)$) in Step 5 of the tone correction procedure; or

b) For tone corrections that occur at one-third-octave bands that are masked or reconstructed, set F equal to zero in Step 9 of the tone correction procedure, and recalculate the maximum tone correction for that spectrum.

Note.- All band levels within a spectrum, whether adjusted, reconstructed, or masked must be included in the computation of the PNL value for that spectrum.

2.6.4.4 ***Handling of masked data in reference conditions data-set***

For any one-third-octave band spectrum adjusted to reference conditions, all bands, including those containing masked levels or reconstructed levels, including values less than 0 dB, must be adjusted for differences between test and reference conditions (i.e., atmospheric absorption and spherical spreading). The special tone correction considerations listed in 2.6.3.2 apply to both test and reference data sets.

2.7 NOISE REDUCTION SYSTEMS

An aircraft can employ noise reduction systems that change its configuration or operating condition to reduce noise, or implement devices or subsystems that directly reduce or counteract noise emissions. Two categories, Variable Noise Reduction Systems (VNRS) and Selectable Noise Reduction Systems (SNRS) have been defined to address differences in activation/actuation for these systems. General guidance on noise certification of aircraft equipped with these systems is provided below.

2.7.1 Variable Noise Reduction Systems

A Variable Noise Reduction System (VNRS) is an integral design feature, or subsystem, of an aircraft that automatically changes the configuration or operating condition of the aircraft to reduce noise.

Note 1.- If pilot action is necessary to activate, i.e. select the use of, an automatically controlled noise reduction system or if a pilot can deactivate (deselect) an automatically controlled noise reduction system, such a system is not considered a VNRS.

Note 2.- Aircraft can incorporate variable systems primarily intended to improve performance, reduce engine emissions and/or increase safety that may also affect noise. Such aircraft can be noise certificated using the guidance provided for aircraft with VNRS. For such changes to existing type designs, the guidelines provided in 1.2 for "No-Acoustical Changes" are applicable.

For a VNRS-equipped aircraft, the VNRS characteristics may prevent flight from being conducted in accordance with the associated reference procedure(s) in the Annex. In such cases, the reference procedures for noise certification of an aircraft with a VNRS should only depart from those specified in the Annex to the extent required by those design characteristics that cause the departure and be approved by the certificating authority (see 3.6.1.4, 5.6.1.4, 8.6.1.4 and 10.5.1.3 of the Annex).

The impacts of a VNRS on noise certification of an aircraft can extend beyond deviations from the Annex 16 Volume I reference procedures. A plan for noise certification of a VNRS equipped aircraft should take into consideration three key elements, namely (1) the necessity, if any, to depart from the Annex reference procedures, (2) the adaptation/modification of test procedures to ensure compliance with Annex requirements, and (3) the applicability of existing procedures in the Annex for adjusting the measured data to reference conditions. Experience to date has shown that one or more of these elements may be inter-related, requiring detailed consideration of all three elements in devising an acceptable plan for noise certification.

2.7.1.1 ***Reference procedures***

The Annex reference procedures typically utilize constant flight path and operational parameters. A VNRS can, however, result in non-constant reference flight paths and/or non-constant operational parameters such as non-constant rates of climb and/or non-constant engine/propeller/rotor speeds, respectively, that compel departures from the reference procedures. In addition to reducing noise emissions, a VNRS may, and typically does, impact aircraft performance during a noise certification reference procedure. In some cases, this impact can be indirect via another affected performance parameter. Both direct and indirect impacts on aircraft performance should be addressed in defining any departures necessary from the reference procedures in the Annex to accommodate a VNRS.

Actuation of a VNRS can be a function of one or more operational conditions such as airspeed, ground speed, height above ground level, density altitude, pressure altitude and ambient temperature. Beginning and end points on the reference flight path for any transition triggered by a VNRS should be determined using the reference test and meteorological conditions.

2.7.1.2 ***Test conditions and procedures***

When a VNRS results in a non-constant reference flight path for the aircraft, the flight path tolerances (height and lateral deviation limits) specified in the Annex for the corresponding constant reference procedure should be applied, subject to approval by the certificating authority. Similarly, when a VNRS results in a non-constant operational parameter for the aircraft, a reference schedule for the affected operating parameter should be defined along the reference flight path and the test tolerances permitted by the Annex for that parameter should be applied to the reference schedule, subject to approval by the certificating authority.

2.7.1.3 ***Adjustments to measured noise data***

Adjustments to measured data in the Annex are based on constant reference procedures. A VNRS can, however, result in a non-constant reference procedure(s) that in turn impacts the adjustments to measured data that account for test deviations from reference flight profiles and test conditions. The adjustments to measured data specified in the Annex should be modified only as necessary to account for any departures from the reference procedures in the Annex. In many cases, only minor changes to data processing software that do not affect the adjustment procedures will be needed. Any modifications, including software revisions, of the adjustments to measured data specified in the Annex, are subject to approval of the certificating authority.

2.7.1.4 ***ETM Guidance for Specific VNRS***

Specific guidance for VNRS technologies will typically be developed as these technologies are developed and implemented in aircraft designs. Cross references to the appropriate sections of this manual for the VNRS technologies for which specific guidance has been generally accepted by certificating authorities are provided in Table 2-5.

Variable Noise Reduction System (VNRS)	Applicable Chapter / Appendix of the Annex	Specific Guidelines Provided in this Manual
Variable Rotor Speed Helicopters	Chapter 8 / Appendix 2	Section 3.1.7 ***AMC No. 2 A2 8.2.1*** [Take-off flight test procedures], Paragraph (8)

Table 2-5 Cross References to Specific Guidelines in this Manual for VNRS

2.7.2 Selectable Noise Reduction Systems

(Reserved)

Note.- The guidance provided in 2.7 addresses Variable Noise Reduction Systems (VNRS) only, and, by inference, defines as selectable all noise reduction systems that do not satisfy the requirements for classification as VNRS. Guidance specific to Selectable Noise Reduction Systems (SNRS), including a definition specific to SNRS, is not yet provided.

2.8 CALCULATION OF THE SPEED OF SOUND

For the purposes of noise certification the value of the speed of sound, c, shall be calculated from the equation taken from ISO 9613-1: 1993(E):

$c = 343.2\ (T/T_0)^{1/2}$ m/s, or

$c = 1125.9\ (T/T_0)^{1/2}$ ft/s,

where $T_0 = 293.15\ K$ and T the absolute ambient air temperature in degrees Kelvin.

Note.- At the noise certification reference temperature of 25°C, T = 298.15°K and c therefore equals 346.1 m/s (1135.5 ft/s).

2.9 REFERENCE TABLES USED IN THE MANUAL CALCULATION OF EFFECTIVE PERCEIVED NOISE LEVEL

Tables 2-6 and 2-7, and Figure 2-6 contain information useful for the manual calculation of Effective Perceived Noise Level. Such manual calculations are often used to verify the accuracy of computer programs used for calculating noise certification levels.

One-third Octave band centre frequencies (Hz)

SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	1000
4																			0.10					
5																		0.10	0.11	0.10				
6																		0.11	0.12	0.11	0.10			
7																		0.12	0.14	0.13	0.11			
8																		0.14	0.16	0.14	0.13			
9																	0.10	0.16	0.17	0.16	0.14			
10																	0.11	0.17	0.19	0.18	0.16	0.10		
11																	0.13	0.19	0.22	0.21	0.18	0.12		
12																0.10	0.14	0.22	0.24	0.24	0.21	0.14		
13																0.11	0.16	0.24	0.27	0.27	0.24	0.16		
14																0.13	0.18	0.27	0.30	0.30	0.27	0.19		
15															0.10	0.14	0.21	0.30	0.33	0.33	0.30	0.22		
16										0.10	0.10	0.10	0.10	0.10	0.11	0.16	0.24	0.33	0.35	0.35	0.33	0.26		
17										0.11	0.11	0.11	0.11	0.11	0.13	0.18	0.27	0.35	0.38	0.38	0.35	0.30	0.10	
18									0.10	0.13	0.13	0.13	0.13	0.13	0.15	0.21	0.30	0.38	0.41	0.41	0.38	0.33	0.12	
19									0.11	0.14	0.14	0.14	0.14	0.14	0.17	0.24	0.33	0.41	0.45	0.45	0.41	0.36	0.14	
20									0.13	0.16	0.16	0.16	0.16	0.16	0.20	0.27	0.36	0.45	0.49	0.49	0.45	0.39	0.17	
21								0.10	0.14	0.18	0.18	0.18	0.18	0.18	0.23	0.30	0.39	0.49	0.53	0.53	0.49	0.42	0.21	0.1
22								0.11	0.16	0.21	0.21	0.21	0.21	0.21	0.26	0.33	0.42	0.53	0.57	0.57	0.53	0.46	0.25	0.1
23								0.13	0.18	0.24	0.24	0.24	0.24	0.24	0.30	0.36	0.46	0.57	0.62	0.62	0.57	0.50	0.30	0.1
24							0.10	0.14	0.21	0.27	0.27	0.27	0.27	0.27	0.33	0.40	0.50	0.62	0.67	0.67	0.62	0.55	0.33	0.1
25							0.11	0.16	0.24	0.30	0.30	0.30	0.30	0.30	0.35	0.43	0.55	0.67	0.73	0.73	0.67	0.60	0.36	0.1
26							0.13	0.18	0.27	0.33	0.33	0.33	0.33	0.33	0.38	0.48	0.60	0.73	0.79	0.79	0.73	0.65	0.39	0.2
27						0.10	0.14	0.21	0.30	0.35	0.35	0.35	0.35	0.35	0.41	0.52	0.65	0.79	0.85	0.85	0.79	0.71	0.42	0.2
28						0.11	0.16	0.24	0.33	0.38	0.38	0.38	0.38	0.38	0.45	0.57	0.71	0.85	0.92	0.92	0.85	0.77	0.46	0.2
29						0.13	0.18	0.27	0.35	0.41	0.41	0.41	0.41	0.41	0.49	0.63	0.77	0.92	1.00	1.00	0.92	0.84	0.50	0.3
30					0.10	0.14	0.21	0.30	0.38	0.45	0.45	0.45	0.45	0.45	0.53	0.69	0.84	1.00	1.07	1.07	1.00	0.92	0.55	0.3
31					0.11	0.16	0.24	0.33	0:41	0.49	0.49	0.49	0.49	0.49	0.57	0.76	0.93	1.07	1.15	1.15	1.07	1.00	0.60	0.3
32					0.13	0.18	0.27	0.36	0.45	0.53	0.53	0.53	0.53	0.53	0.62	0.83	1.00	1.15	1.23	1.23	1.15	1.07	0.65	0.4
33					0.14	0.21	0.30	0.39	0.49	0.57	0.57	0.57	0.57	0.57	0.67	0.91	1.07	1.23	1.32	1.32	1.23	1.15	0.71	0.4
34				0.10	0.16	0.24	0.33	0.42	0.53	0.62	0.62	0.62	0.62	0.62	0.73	1.00	1.15	1.32	1.41	1.41	1.32	1.23	0.77	0.5
35				0.11	0.18	0.27	0.36	0.46	0.57	0.67	0.67	0.67	0.67	0.67	0.79	1.07	1.23	1.41	1.51	1.51	1.41	1.32	0.84	0.5
36				0.13	0.21	0.30	0.40	0.50	0.62	0.73	0.73	0.73	0.73	0.73	0.85	1.15	1.32	1.51	1.62	1.62	1.51	1.41	0.92	0.6
37				0.15	0.24	0.33	0.43	0.55	0.67	0.79	0.79	0.79	0.79	0.79	0.92	1.23	1.41	1.62	1.74	1.74	1.62	1.51	1.00	0.6
38				0.17	0.27	0.37	0.48	0.60	0.73	0.85	0.85	0.85	0.85	0.85	1.00	1.32	1.51	1.74	1.86	1.86	1.74	1.62	1.10	0.7
39			0.10	0.20	0.30	0.41	0.52	0.65	0.79	0.92	0.92	0.92	0.92	0.92	1.07	1.41	1.62	1.86	1.99	1.99	1.86	1.74	1.21	0.8
40			0.12	0.23	0.33	0.45	0.57	0.71	0.85	1.00	1.00	1.00	1.00	1.00	1.15	1.51	1.74	1.99	2.14	2.14	1.99	1.86	1.34	0.9
41			0.14	0.26	0.37	0.50	0.63	0.77	0.92	1.07	1.07	1.07	1.07	1.07	1.23	1.62	1.86	2.14	2.29	2.29	2.14	1.99	1.48	1.0
42			0.16	0.30	0.41	0.55	0.69	0.84	1.00	1.15	1.15	1.15	1.15	1.15	1.32	1.74	1.99	2.29	2.45	2.45	2.29	2.14	1.63	1.1
43			0.19	0.33	0.45	0.61	0.76	0.92	1.07	1.23	1.23	1.23	1.23	1.23	1.41	1.86	2.14	2.45	2.63	2.63	2.45	2.29	1.79	1.2
44		0.10	0.22	0.37	0.50	0.67	0.83	1.00	1.15	1.32	1.32	1.32	1.32	1.32	1.52	1.99	2.29	2.63	2.81	2.81	2.63	2.45	1.99	1.3
45		0.12	0.26	0.42	0.55	0.74	0.91	1.08	1.24	1.41	1.41	1.41	1.41	1.41	1.62	2.14	2.45	2.81	3.02	3.02	2.81	2.63	2.14	1.4
46		0.14	0.30	0.46	0.61	0.82	1.00	1.16	1.33	1.52	1.52	1.52	1.52	1.52	1.74	2.29	2.63	3.02	3.23	3.23	3.02	2.81	2.29	1.6
47		0.16	0.34	0.52	0.67	0.90	1.08	1.25	1.42	1.62	1.62	1.62	1.62	1.62	1.87	2.45	2.81	3.23	3.46	3.46	3.23	3.02	2.45	1.7
48		0.19	0.38	0.58	0.74	1.00	1.17	1.34	1.53	1.74	1.74	1.74	1.74	1.74	2.00	2.63	3.02	3.46	3.71	3.71	3.46	3.23	2.63	1.9
49	0.10	0.22	0.43	0.65	0.82	1.08	1.26	1.45	1.64	1.87	1.87	1.87	1.87	1.87	2.14	2.81	3.23	3.71	3.97	3.97	3.71	3.46	2.81	2.1
50	0.12	0.26	0.49	0.72	0.90	1.17	1.36	1.56	1.76	2.00	2.00	2.00	2.00	2.00	2.30	3.02	3.46	3.97	4.26	4.26	3.97	3.71	3.02	2.4
51	0.14	0.30	0.55	0.80	1.00	1.26	1.47	1.68	1.89	2.14	2.14	2.14	2.14	2.14	2.46	3.23	3.71	4.26	4.56	4.56	4.26	3.97	3.23	2.6
52	0.17	0.34	0.62	0.90	1.08	1.36	1.58	1.80	2.03	2.30	2.30	2.30	2.30	2.30	2.64	3.46	3.97	4.56	4.89	4.89	4.56	4.26	3.46	2.8
53	0.21	0.39	0.70	1.00	1.18	1.47	1.71	1.94	2.17	2.46	2.46	2.46	2.46	2.46	2.83	3.71	4.26	4.89	5.24	5.24	4.89	4.56	3.71	3.0
54	0.25	0.45	0.79	1.09	1.28	1.58	1.85	2.09	2.33	2.64	2.64	2.64	2.64	2.64	3.03	3.97	4.56	5.24	5.61	5.61	5.24	4.89	3.97	3.2
55	0.30	0.51	0.89	1.15	1.35	1.71	2.00	2.25	2.50	2.83	2.83	2.83	2.83	2.83	3.25	4.26	4.89	5.61	6.01	6.01	5.61	5.24	4.26	3.4
56	0.34	0.59	1.00	1.29	1.50	1.85	2.15	2.42	2.69	3.03	3.03	3.03	3.03	3.03	3.48	4.56	5.24	6.01	6.44	6.44	6.01	5.61	4.56	3.7
57	0.39	0.67	1.09	1.40	1.63	2.00	2.33	2.61	2.88	3.25	3.25	3.25	3.25	3.25	3.73	4.89	5.61	6.44	6.90	6.90	6.44	6.01	4.89	3.9
58	0.45	0.77	1.18	1.53	1.77	2.15	2.51	2.81	3.10	3.48	3.48	3.48	3.48	3.48	4.00	5.24	6.01	6.90	7.39	7.39	6.90	6.44	5.24	4.2
59	0.51	0.87	1.29	1.66	1.92	2.33	2.71	3.03	3.32	3.73	3.73	3.73	3.73	3.73	4.29	5.61	6.44	7.39	7.92	7.92	7.39	6.90	5.61	4.5

Table 2-6. Perceived noisiness (noys) as a function of sound pressure level

One-third Octave band centre frequencies (Hz)

SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	100
60	0.59	1.00	1.40	1.81	2.08	2.51	2.93	3.26	3.57	4.00	4.00	4.00	4.00	4.00	4.59	6.01	6.90	7.92	8.49	8.49	7.92	7.39	6.01	4.8
61	0.67	1.10	1.53	1.97	2.26	2.71	3.16	3.51	3.83	4.29	4.29	4.29	4.29	4.29	4.92	6.44	7.39	8.49	9.09	9.09	8.49	7.92	6.44	5.2
62	0.77	1.21	1.66	2.15	2.45	2.93	3.41	3.78	4.11	4.59	4.59	4.59	4.59	4.59	5.28	6.90	7.92	9.09	9.74	9.74	9.09	8.49	6.90	5.6
63	0.87	1.32	1.81	2.34	2.65	3.16	3.69	4.06	4.41	4.92	4.92	4.92	4.92	4.92	5.66	7.39	8.49	9.74	10.4	10.4	9.74	9.09	7.39	6.0
64	1.00	1.45	1.97	2.54	2.88	3.41	3.98	4.38	4.73	5.28	5.28	5.28	5.28	5.28	6.06	7.92	9.09	10.4	11.2	11.2	10.4	9.74	7.92	6.4
65	1.11	1.60	2.15	2.77	3.12	3.69	4.30	4.71	5.08	5.66	5.66	5.66	5.66	5.66	6.50	8.49	9.74	11.2	12.0	12.0	11.2	10.4	8.49	6.9
66	1.22	1.75	2.34	3.01	3.39	3.99	4.64	5.07	5.45	6.06	6.06	6.06	6.06	6.06	6.96	9.09	10.4	12.0	12.8	12.8	12.0	11.2	9.09	7.3
67	1.35	1.92	2.54	3.28	3.68	4.30	5.01	5.46	5.85	6.50	6.50	6.50	6.50	6.50	7.46	9.74	11.2	12.8	13.8	13.8	12.8	12.0	9.74	7.9
68	1.49	2.11	2.77	3.57	3.99	4.64	5.41	5.88	6.27	6.96	6.96	6.96	6.96	6.96	8.00	10.4	12.0	13.8	14.7	14.7	13.8	12.8	10.4	8.4
69	1.65	2.32	3.01	3.88	4.33	5.01	5.84	6.33	6.73	7.46	7.46	7.46	7.46	7.46	8.57	11.2	12.8	14.7	15.8	15.8	14.7	13.8	11.2	9.0
70	1.82	2.55	3.28	4.23	4.69	5.41	6.31	6.81	7.23	8.00	8.00	8.00	8.00	8.00	9.19	12.0	13.8	15.8	16.9	16.9	15.8	14.7	12.0	9.7
71	2.02	2.79	3.57	4.60	5.09	5.84	6.81	7.33	7.75	8.57	8.57	8.57	8.57	8.57	9.85	12.8	14.7	16.9	18.1	18.1	16.9	15.8	12.8	10.
72	2.23	3.07	3.88	5.01	5.52	6.31	7.36	7.90	8.32	9.19	9.19	9.19	9.19	9.19	10.6	13.8	15.8	18.1	19.4	19.4	18.1	16.9	13.8	11.
73	2.46	3.37	4.23	5.45	5.99	6.81	7.94	8.50	8.93	9.85	9.85	9.85	9.85	9.85	11.3	14.7	16.9	19.4	20.8	20.8	19.4	18.1	14.7	12.
74	2.72	3.70	4.60	5.94	6.50	7.36	8.57	9.15	9.59	10.6	10.6	10.6	10.6	10.6	12.1	15.8	18.1	20.8	22.3	22.3	20.8	19.4	15.8	12.
75	3.01	4.06	5.01	6.46	7.05	7.94	9.19	9.85	10.3	11.3	11.3	11.3	11.3	11.3	13.0	16.9	19.4	22.3	23.9	23.9	22.3	20.8	16.9	13.
76	3.32	4.46	5.45	7.03	7.65	8.57	9.85	10.6	11.0	12.1	12.1	12.1	12.1	12.1	13.9	18.1	20.8	23.9	25.6	25.6	23.9	22.3	18.1	14.
77	3.67	4.89	5.94	7.66	8.29	9.19	10.6	11.3	11.8	13.0	13.0	13.0	13.0	13.0	14.9	19.4	22.3	25.6	27.4	27.4	25.6	23.9	19.4	15.
78	4.06	5.37	6.46	8.33	9.00	9.85	11.3	12.1	12.7	13.9	13.9	13.9	13.9	13.9	16.0	20.8	23.9	27.4	29.4	29.4	27.4	25.6	20.8	16.
79	4.49	5.90	7.03	9.07	9.76	10.6	12.1	13.0	13.6	14.9	14.9	14.9	14.9	14.9	17.1	22.3	25.6	29.4	31.5	31.5	29.4	27.4	22.3	18.
80	4.96	6.48	7.66	9.85	10.6	11.3	13.0	13.9	14.6	16.0	16.0	16.0	16.0	16.0	16.4	23.9	27.4	31.5	33.7	33.7	31.5	29.4	23.9	19.
81	5.48	7.11	8.33	10.6	11.3	12.1	13.9	14.9	15.7	17.1	17.1	17.1	17.1	17.1	19.7	25.6	29.4	33.7	36.1	36.1	33.7	31.5	25.6	20.
82	6.06	7.81	9.07	11.3	12.1	13.0	14.9	16.0	16.9	18.4	18.4	18.4	18.4	18.4	21.1	27.4	31.5	36.1	38.7	38.7	36.1	33.7	27.4	22.
83	6.70	8.57	9.87	12.1	13.0	13.9	16.0	17.1	18.1	19.7	19.7	19.7	19.7	19.7	22.6	29.4	33.7	38.7	41.5	41.5	38.7	36.1	29.4	23.
84	7.41	9.41	10.7	13.0	13.9	14.9	17.1	18.4	19.4	21.1	21.1	21.1	21.1	21.1	24.3	31.5	36.1	41.5	44.4	44.4	41.5	38.7	31.5	25.
85	8.19	10.3	11.7	13.9	14.9	16.0	18.4	19.7	20.8	22.6	22.6	22.6	22.6	22.6	26.0	33.7	38.7	44.4	47.6	47.6	44.4	41.5	33.7	27.
86	9.05	11.3	12.7	14.9	16.0	17.1	19.7	21.1	22.4	24.3	24.3	24.3	24.3	24.3	27.9	36.1	41.5	47.6	51.0	51.0	47.6	44.4	36.1	29.
87	10.0	12.1	13.9	16.0	17.1	18.4	21.1	22.6	24.0	26.0	26.0	26.0	26.0	26.0	29.9	38.7	44.4	51.0	54.7	54.7	51.0	47.6	38.7	31.
88	11.1	13.0	14.9	17.1	18.4	19.7	22.6	24.3	25.8	27.9	27.9	27.9	27.9	27.9	32.0	41.5	47.6	54.7	58.6	58.6	54.7	51.0	41.5	33.
89	12.2	13.9	16.0	18.4	19.7	21.1	24.3	26.0	27.7	29.9	29.9	29.9	29.9	29.9	34.3	44.4	51.0	58.6	62.7	62.7	58.6	54.7	44.4	36.
90	13.5	14.9	17.1	19.7	21.1	22.6	26.0	27.9	29.7	32.0	32.0	32.0	32.0	32.0	36.8	47.6	54.7	62.7	67.2	67.2	62.7	58.6	47.6	38.
91	14.9	16.0	18.4	21.1	22.6	24.3	27.9	29.9	31.8	34.3	34.3	34.3	34.3	34.3	39.4	51.0	58.6	67.2	72.0	72.0	67.2	62.7	51.0	41.
92	16.0	17.1	19.7	22.6	24.3	26.0	29.9	32.0	34.2	36.8	36.8	36.8	36.8	36.8	42.2	54.7	62.7	72.0	77.2	77.2	72.0	67.2	54.7	44.
93	17.1	18.4	21.1	24.3	26.0	27.9	32.0	34.3	36.7	39.4	39.4	39.4	39.4	39.4	45.3	58.6	67.2	77.2	82.7	82.7	77.2	72.0	58.6	47.
94	18.4	19.7	22.6	26.0	27.9	29.9	34.3	36.8	39.4	42.2	42.2	42.2	42.2	42.2	48.5	62.7	72.0	82.7	88.6	88.6	82.7	77.2	62.7	51.
95	19.7	21.1	24.3	27.9	29.9	32.0	36.8	39.4	42.2	45.3	45.3	45.3	45.3	45.3	52.0	67.2	77.2	88.6	94.9	94.9	88.6	82.7	67.2	54.
96	21.1	22.6	26.0	29.9	32.0	34.3	39.4	42.2	45.3	48.5	48.5	48.5	48.5	48.5	55.7	72.0	82.7	94.9	102	102	94.9	88.6	72.0	58.
97	22.6	24.3	27.9	32.0	34.3	36.8	42.2	45.3	48.5	52.0	52.0	52.0	52.0	52.0	59.7	77.2	88.6	102	109	109	102	94.9	77.2	62.
98	24.3	26.0	29.9	34.3	36.8	39.4	45.3	48.5	52.0	55.7	55.7	55.7	55.7	55.7	64.0	82.7	94.9	109	117	117	109	102	82.7	67.
99	26.0	27.9	32.0	36.8	39.4	42.2	48.5	52.0	55.7	59.7	59.7	59.7	59.7	59.7	68.6	88.6	102	117	125	125	117	109	88.6	72.
100	27.9	29.9	34.3	39.4	42.2	45.3	52.0	55.7	59.7	64.0	64.0	64.0	64.0	64.0	73.5	94.9	109	125	134	134	125	117	94.9	77.
101	29.9	32.0	36.8	42.2	45.3	48.5	55.7	59.7	64.0	68.6	68.6	68.6	68.6	68.6	78.8	102	117	134	144	144	134	125	102	82.
102	32.0	34.3	39.4	45.3	48.5	52.0	59.7	64.0	68.6	73.5	73.5	73.5	73.5	73.5	84.4	109	125	144	154	154	144	134	109	88.
103	34.3	36.8	42.2	48.5	52.0	55.7	64.0	68.6	73.5	78.8	78.8	78.8	78.8	78.8	90.5	117	134	154	165	165	154	144	117	94.
104	36.8	39.4	45.3	52.0	55.7	59.7	68.6	73.5	78.8	84.4	84.4	84.4	84.4	84.4	97.0	125	144	165	177	177	165	154	125	1
105	39.4	42.2	48.5	55.7	59.7	64.0	73.5	78.8	84.4	90.5	90.5	90.5	90.5	90.5	104	134	154	177	189	189	177	165	134	1
106	42.2	45.3	52.0	59.7	64.0	68.6	78.8	84.4	90.5	97.0	97.0	97.0	97.0	97.0	111	144	165	189	203	203	189	177	144	11
107	45.3	46.5	55.7	64.0	68.6	73.5	84.4	90.5	97.0	104	104	104	104	104	119	154	177	203	217	217	203	189	154	1
108	48.5	52.0	59.7	68.6	73.5	78.8	90.5	97.0	104	111	111	111	111	111	128	165	189	217	233	233	217	203	165	1
109	52.0	55.7	64.0	73.5	78.8	84.4	97.0	104	111	119	119	119	119	119	137	177	203	233	249	249	233	217	177	1
110	55.7	59.7	68.6	78.8	84.4	90.5	104	111	119	128	128	128	128	128	147	189	217	249	267	267	249	233	189	1
111	59.7	64.0	73.5	84.4	90.5	97.0	111	119	128	137	137	137	137	137	158	203	233	267	286	286	267	249	203	1
112	64.0	68.6	78.8	90.5	97.0	104	119	128	137	147	147	147	147	147	169	217	249	286	307	307	286	267	217	1
113	68.6	73.5	84.4	97.0	104	111	128	137	147	158	158	158	158	158	181	233	267	307	329	329	307	286	233	1
114	73.5	78.8	90.5	104	111	119	137	147	158	169	169	169	169	169	194	249	286	329	352	352	329	307	243	2
115	78.8	84.4	97.0	111	119	128	147	158	169	181	181	181	181	181	208	267	307	352	377	377	352	329	267	2
116	84.4	90.5	104	119	128	137	158	169	181	194	194	194	194	194	223	286	329	377	404	404	377	352	286	2
117	90.5	97.0	111	128	137	147	169	181	194	208	208	208	208	208	239	307	352	404	433	433	404	377	307	2
118	97.0	104	119	137	147	158	181	194	208	223	223	223	223	223	256	329	377	433	464	464	433	404	329	2
119	104	111	128	147	158	169	194	208	223	239	239	239	239	239	274	352	404	464	497	497	464	433	352	2

Table 2-6. continued

One-third Octave band centre frequencies (Hz)

SPL	50	63	80	100	125	160	200	250	315	400	500	630	800	1000	1250	1600	2000	2500	3150	4000	5000	6300	8000	10
120	111	119	137	158	169	181	208	223	239	256	256	256	256	256	294	377	433	497	533	533	497	464	377	3
121	119	128	147	169	181	194	223	239	256	274	274	274	274	274	315	404	464	533	571	571	533	497	404	3
122	128	137	158	181	194	208	239	256	274	294	294	294	294	294	338	433	497	571	611	611	571	533	433	3
123	137	147	169	194	208	223	256	274	294	315	315	315	315	315	362	464	533	611	655	655	611	571	464	3
124	147	158	181	208	223	239	274	294	315	338	338	338	338	338	388	497	571	655	702	702	655	611	497	4
125	158	169	194	223	239	256	294	315	338	362	362	362	362	362	416	533	611	702	752	752	702	655	533	4
126	169	181	208	239	256	274	315	338	362	388	388	388	388	388	446	571	655	752	806	806	752	702	571	4
127	181	194	223	256	274	294	338	362	388	416	416	416	416	416	478	611	702	806	863	863	806	752	611	4
128	194	208	239	274	294	315	362	388	416	446	446	446	446	446	512	655	752	863	925	925	863	806	655	5
129	208	223	256	294	315	338	388	416	446	478	478	478	478	478	549	702	806	925	991	991	925	863	702	5
130	223	239	274	315	338	362	416	446	478	512	512	512	512	512	588	752	863	991	1062	1062	991	925	752	6
131	239	256	294	338	362	388	446	478	512	549	549	549	549	549	630	806	925	1062	1137	1137	1062	991	806	6
132	256	274	315	362	388	416	478	512	549	588	588	588	588	588	676	863	991	1137	1219	1219	1137	1062	863	7
133	274	294	338	388	416	446	512	549	588	630	630	630	630	630	724	925	1062	1219	1306	1306	1219	1137	925	7
134	294	315	362	416	446	478	549	588	630	676	676	676	676	676	776	991	1137	1306	1399	1399	1306	1219	991	8
135	315	338	388	446	478	512	588	630	676	724	724	724	724	724	832	1062	1219	1399	1499	1499	1399	1306	1062	8
136	338	362	416	478	512	549	630	676	724	776	776	776	776	776	891	1137	1306	1499	1606	1606	1499	1399	1137	9
137	362	388	446	512	549	588	676	724	776	832	832	832	832	832	955	1219	1399	1606	1721	1721	1606	1499	1219	9
138	388	416	478	549	588	630	724	776	832	891	891	891	891	891	1024	1306	1499	1721	1844	1844	1721	1606	1306	10
139	416	446	512	588	630	676	776	832	891	955	955	955	955	955	1098	1399	1606	1844	1975	1975	1844	1721	1399	11
140	446	478	549	630	676	724	832	891	955	1024	1024	1024	1024	1024	1176	1499	1721	1975			1975	1844	1499	1
141	478	512	588	676	724	776	891	955	1024	1098	1098	1098	1098	1098	1261	1606	1844					1975	1606	1
142	512	549	630	724	776	832	955	1024	1098	1176	1176	1176	1176	1176	1351	1721	1975						1721	1
143	549	588	676	776	832	891	1024	1098	1176	1261	1261	1261	1261	1261	1448	1844							1844	1
144	588	630	724	832	891	955	1098	1176	1261	1351	1351	1351	1351	1351	1552	1975							1975	1
145	630	676	776	891	955	1024	1176	1261	1351	1448	1448	1488	1448	1448	1664									1
146	676	724	832	955	1024	1098	1261	1351	1448	1552	1552	1552	1552	1552	1783									1
147	724	776	891	1024	1098	1176	1351	1448	1552	1664	1664	1664	1664	1664	1911									1
148	776	832	955	1098	1176	1261	1448	1552	1664	1783	1783	1783	1783	1783	2040									
149	832	891	1024	1176	1261	1351	1552	1664	1783	1911	1911	1911	1911	1911										
150	891	955	1098	1261	1351	1448	1664	1783	1911	2048	2048	2048	2048	2048										

Table 2-6. continued

①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩	⑪
Band (*i*)	*f* Hz	SPL dB	S dB Step 1	|ΔS| dB Step 2	SPL' dB Step 4	S' dB Step 5	S̄ dB Step 6	SPL" dB Step 7	*F* dB Step 8	*C* dB Step 9
1	50	-	-	-	-	-	-	-	-	-
2	63	-	-	-	-	-	-	-	-	-
3	80	70	-	-	70	-8	-2⅓	70	-	
4	100	62	-8	-	62	-8	+3⅓	67⅔	-	
5	125	(70)	+⑧	16	71	+9	+6⅔	71	-	
6	160	80	+10	2	80	+9	+2⅔	77⅔	2⅓	0.29
7	200	82	+②	8	82	+2	-1⅓	80⅓	1⅔	0.06
8	250	(83)	+1	1	79	-3	-1⅓	79	4	0.61
9	315	76	-⑦	8	76	-3	+⅓	77⅔	-	
10	400	(80)	+④	11	78	+2	+1	78	2	0.17
11	500	80	0	4	80	+2	0	79	-	
12	630	79	-1	1	79	-1	0	79	-	
13	800	78	-1	0	78	-1	-⅓	79	-	
14	1000	80	+2	3	80	+2	-⅔	78⅔		
15	1250	78	-2	4	78	-2	-⅓	78	-	
16	1600	76	-2	0	76	-2	+⅓	77⅔	-	
17	2000	79	+3	5	79	+3	+1	78		
18	2500	(85)	+6	3	79	0	-⅓	79	6	[2]
19	3150	79	-⑥	12	79	0	-2⅔	78⅔	-	
20	4000	78	-1	5	78	-1	-6⅓	76	2	0.33
21	5000	71	-⑦	6	71	-7	-8	69⅔	-	
22	6300	60	-11	4	60	-11	-8⅔	61⅔	-	
23	8000	54	-6	5	54	-6	-8	53		
24	10000	45	-9	3	45	-9	-	45	-	
						-9				

Step 1	③ (*i*)-③ (*i*-1)
Step 2	|④ (*i*)-④ (*i*-1)|
Step 3	See instructions
Step 4	See instructions
Step 5	⑥ (*i*)-⑥ (*i*-1)

Step 6	[⑦ (*i*) +⑦ (*i*+1) +⑦ (*i*+2)] ÷ 3
Step 7	⑨ (*i*-1)+⑧ (*i*-1)
Step 8	③ (*i*) - ⑨ (*i*)
Step 9	See Table A2-2 of Appendix 2 of the Annex

Note.- Steps 5 and 6 may be eliminated in the calculations if desired. In this case in the example shown, columns ⑦ and ⑧ should be removed and existing columns ⑨, ⑩ and ⑪ become ⑦, ⑧ and ⑨ covering new steps5, 6 and 7 respectively. The existing steps 5, 6, 7, 8 and 9 in 4.3.1 of Appendix 2 of the Annex are then replaced by:

Step 5 [⑥ (*i*-1) +⑥ (*i*) +⑥ (*i*+1)] ÷ 3
Step 6 ③ (*i*)-⑦ (*i*) if > 0
Step 7 See Table A2-2 of Appendix 2 of the Annex

Table 2-7. Example of tone correction calculation for a turbofan engine

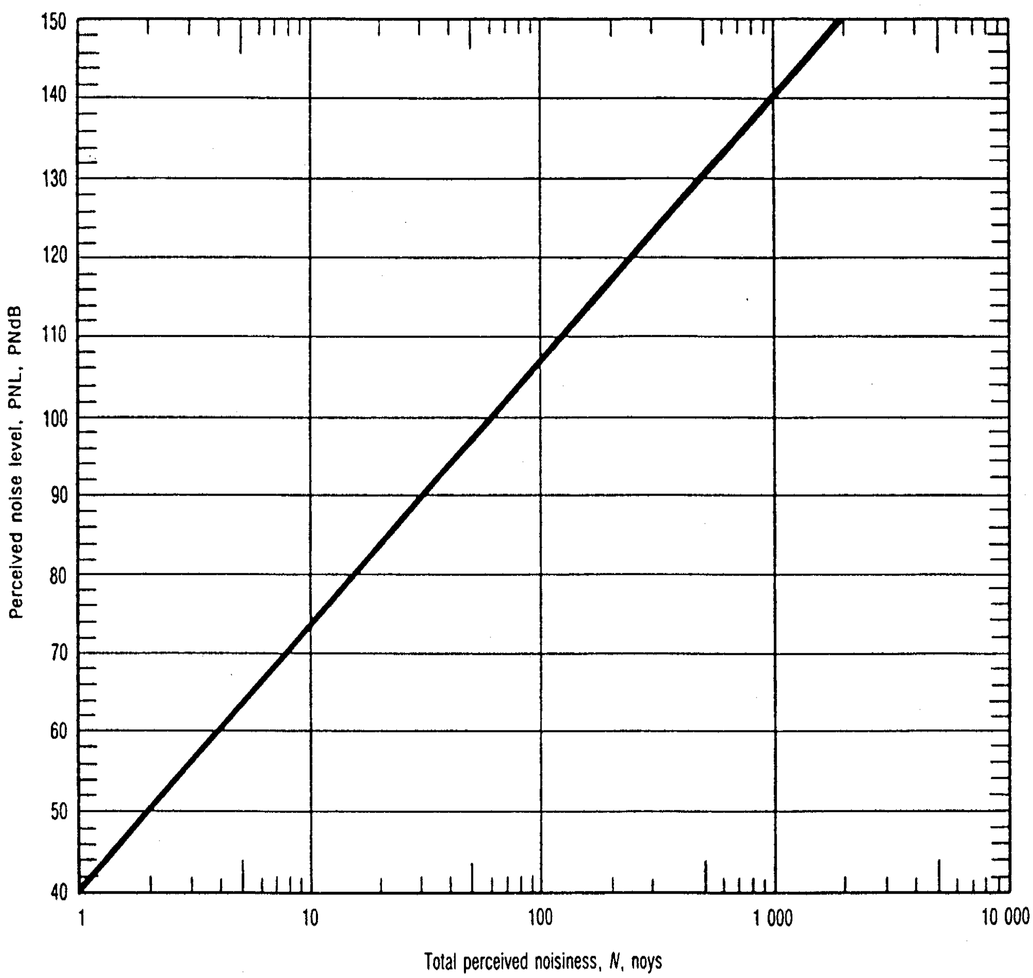


Figure 2-6 Perceived noise level as a function of total perceived noisiness

Chapter 3

GUIDELINES FOR SUBSONIC JET AEROPLANES, PROPELLER-DRIVEN AEROPLANES OVER 8618 kg, AND HELICOPTERS EVALUATED UNDER APPENDIX 2 OF ICAO ANNEX 16, VOLUME I

3.1 EXPLANATORY INFORMATION

3.1.1 Noise certification test and measurement conditions

AMC A2 2.1
[General]

(1) Applicant's Responsibility

An applicant should prepare a noise compliance demonstration plan as described in 1.4 that specifies a proposed certification process, including equivalencies. This plan is to be submitted to the appropriate certificating authority allowing sufficient time to permit adequate review and possible revisions prior to the start of any noise certification testing.

GM A2 2.2.1
[Test Site Selection]

Section 2.1 provides guidance that applicants should follow in selecting a noise certification test site suitable for the testing of subsonic jet aeroplanes, propeller-driven aeroplanes over 8618 kg, and helicopters evaluated under Appendix 2 of the Annex.

GM A2 2.2.2.2a
[No precipitation]

(1) Effects of Moisture on Microphones

Most microphones that are used during noise certification testing are susceptible to moisture. Precipitation, including snow, drizzle and fog, or excessive humidity may induce electrical arcing of the microphone sensors, making measured noise data unacceptable. However, some pre-polarized microphones are less susceptible to electrical arcing during high-moisture conditions (consult the equipment manufacturer's specifications). Special care should be taken to ensure that any windscreens exposed to precipitation be thoroughly dry, inside and out, before use. Foam windscreens can trap water and wet foam windscreens should be avoided.

(2) Microphone Internal Heaters

When internal heaters are provided, microphones are less likely to be affected by moisture in wet, humid, cold or freezing atmospheric conditions.

AMC A2 2.2.2.2a
[No precipitation]

(1) Precautions

Special precautions should be taken by the applicant to protect microphones when a test shutdown is caused by wet, humid or near freezing atmospheric conditions. Measurement system components should be thoroughly dry before testing is resumed to prevent arcing.

GM A2 2.2.2.2b
[Ambient air temperature]

(1) Assumed Ground Atmospheric Conditions

The temperature and relative humidity near the earth's surface can be affected by numerous factors, including solar heating, surface winds, local heating or cooling, increased or decreased local humidity etc. To avoid localized anomalous conditions that often occur near the ground, meteorological measurements are to be made 10 m (33 ft) above the surface. During processing of acoustical data, the meteorological conditions measured at 10 m (33 ft) are assumed to be constant from that height down to the ground surface.

(2) Criteria for Measuring Atmospheric Conditions

Experience has shown that proper measurement of non-reference meteorological conditions and the associated adjustment of noise data for these conditions are crucial to obtaining accurate, consistent and repeatable test results. For aeroplanes, meteorological observations of the temperature and relative humidity are required over the whole sound propagation path from the aircraft to the vicinity of the noise measurement points. For helicopters, temperature and relative humidity measurements are required at 10 m (33 ft) in the vicinity of the noise measurement points.

AMC A2 2.2.2.2b
[Ambient air temperature]

(1) Atmospheric Measurements

Several methods have been approved for the measurement of atmospheric conditions from 10 m (33 ft) above the ground to the altitude of the test aeroplane. Some applicants have used instrumented balloons. Another method consists of a meteorological aeroplane, manned or un-manned, flown in a spiral flight path in the vicinity of the noise measurement points to measure the dry bulb temperature and dew point along the sound propagation path.

AMC A2 2.2.2.2d
[Calculation of sound attenuation coefficients for the effects of atmospheric absorption]

(1) Basic data

Measurements of the ambient temperature and relative humidity should be made at 10 m (33 ft) above the ground. The ambient temperature and relative humidity should also be determined with vertical height increments not greater than 30 m (100 ft) over the sound propagation path. All measurements of ambient temperature and relative humidity shall be obtained within 30 minutes of each aeroplane test run

(2) Determination of the average sound attenuation coefficient

Table 3-1 is an example of calculation of sound attenuation coefficients in the 3150 Hz one-third octave band for an aeroplane approach noise certification when multiple layering is not required. Temperature and humidity values obtained from atmospheric soundings performed before and after a series of aeroplane test runs are interpolated to the time of PNLTM.

The individual coefficients shown in Table 3-1 are calculated at vertical height increments of 30 m from 10 m to a height of 150 m. The ambient conditions from the ground to 10 m are assumed to be those measured at 10 m.

Height (m)	Temperature (°C)	RH (%)	α (3150 Hz) (dB/100m)
10	14.1	50	2.45
30	13.4	53	2.38
60	12.9	56	2.30
90	12.2	57	2.33
120	11.5	58	2.37
150	11.3	61	2.27

Table 3-1 Basic data (layering not required)

The individual sound attenuation coefficients for the 3150 Hz one-third octave band shown in Table 3-1 vary by less than 0.5 dB/100 m relative to the value determined at 10 m (33 ft). In this case the coefficient to be used for adjustment of sound pressure levels from test to reference conditions is the average of the coefficients at 10 m (33 ft) and at the height of the aeroplane at the time of PNLTM.

For this example, the height of the test aeroplane at the time of PNLTM is 125 m. The associated attenuation coefficient is calculated by linear interpolation as follows:

$$y = y_a + \frac{(x - x_a) \times (y_b - y_a)}{(x_b - x_a)}$$

$$\alpha(3150)_{125m} = 2.37 + \frac{(125 - 120) \times (2.27 - 2.37)}{(150 - 120)}$$

$$\alpha(3150)_{125m} = 2.35 \text{ dB/100m}$$

Then the average attenuation coefficient for the 3150 Hz one-third octave band used for adjustment of the aeroplane sound pressure levels is calculated as follows:

$$\overline{\alpha(3150)} = \frac{\alpha(3150)_{10m} + \alpha(3150)_{125m}}{2}$$

$$\overline{\alpha(3150)} = \frac{2.45 + 2.35}{2}$$

$$\overline{\alpha(3150)} = 2.40 \text{ dB/100m}$$

The coefficients for the other one-third-octave bands are determined in a similar manner. These average coefficients are then used in the adjustment of aeroplane SPLs to reference conditions. The same general procedure would be used if no layering is required for determining the average coefficients during flyover and lateral noise certification measurements.

(3) Determination of the cumulative sound attenuation coefficients

Table 3-2 is an example of calculation of sound attenuation coefficients in the 3150 Hz one-third octave band for an aeroplane flyover noise certification when multiple layering is required. Temperature and humidity values obtained from atmospheric soundings performed before and after a series of aeroplane test runs are interpolated to the time of PNLTM.

The individual coefficients shown in Table 3-2 are calculated at vertical height increments of 30 m from 10 m to a height of 420 m. The ambient conditions from the ground to 10 m are assumed to be those measured at 10 m.

The individual sound attenuation coefficients for the 3150 Hz one-third octave band shown in Table 3-2 vary by more than 0.5 dB/100 m. In this case the coefficient to be used for adjustment of sound pressure levels from test to reference conditions is the cumulative sound attenuation from the ground to the height of the aeroplane at the time of PNLTM.

In the absence of extreme or anomalous conditions (e.g. large variations in, or inversions of, temperature and/or humidity), which will generally be the case, it is acceptable, subject to the approval of the certificating authority, to determine the cumulative sound attenuation coefficients for each one-third octave band from a simple average of the coefficients at the boundaries of each layer.

Where extreme or anomalous conditions are present (e.g. large variations in, or inversions of, temperature and/or humidity) the cumulative sound attenuation coefficients for each one-third octave band should be determined by apportioning the sound attenuation coefficients for each layer. Table 3-3 illustrates an example of such a method

The atmosphere is first divided into layers from the ground to the aeroplane height. For this example the height of the aeroplane at the time of PNLTM is 411 m.

The sound attenuation coefficient at the height of the test aeroplane is calculated by linear interpolation of the sound attenuation coefficients at the upper and lower boundaries of the uppermost layer.

Height (m)	**Temperature (°C)**	**RH (%)**	**α (3150 Hz) (dB/100m)**
10	7.2	80	2.09
30	7.2	75	2.23
60	8.9	73	2.11
90	10.0	67	2.19
120	10.6	63	2.27
150	10.6	62	2.31
180	10.6	61	2.34
210	10.6	59	2.43
240	11.1	55	2.57
270	11.7	53	2.59
300	11.7	51	2.70
330	11.1	51	2.79
360	11.1	50	2.84
390	11.1	47	3.04
420	11.1	46	3.10

Table 3-2 Basic data (layering required)

The effective layer depth is determined as follows: For all layers between the aeroplane and the microphone, except the lowest layer containing the microphone, and the uppermost layer containing the aeroplane, the effective layer depth is the full 30 m; for the lowest layer, containing the microphone, the effective layer depth is 30 m minus the 1.2 m height of the microphone; for the uppermost layer, containing the aeroplane, the effective layer depth is the height of the aeroplane minus the height of the lower boundary of the layer.

The effective layer depth proportion for each layer is determined as the ratio of that layer's effective depth relative to the total vertical component of the sound propagation distance from the microphone to the height of the aeroplane at the time of PNLTM.

The average sound attenuation coefficient for each layer is obtained by averaging the coefficients at the upper and lower boundaries of the layer.

The apportioned sound attenuation coefficient for each layer is obtained by multiplying the average layer sound attenuation coefficient by the effective layer depth proportion.

The summation of all apportioned sound attenuation coefficients results in the cumulative sound attenuation coefficient. In this example the cumulative coefficient is calculated for the 3150 Hz one-third octave band. The same general procedure would be used to obtain the cumulative sound attenuation coefficient for each one-third octave band. These coefficients are then used in the adjustment of aeroplane SPLs to reference conditions.

Layer boundaries	Effective layer depth (m)	Effective layer depth proportion (%)	Sound attenuation coefficients, α (3150 Hz) (dB/100m)	Average layer sound attenuation coefficients, α (3150 Hz) (dB/100m)	Apportioned sound attenuation coefficients, α (3150 Hz) (dB/100m)
0-30	28.8	7.03	2.09-2.23	2.16	0.1518
30-60	30.0	7.32	2.23-2.11	2.17	0.1589
60-90	30.0	7.32	2.11-2.19	2.15	0.1574
90-120	30.0	7.32	2.19-2.27	2.23	0.1633
120-150	30.0	7.32	2.27-2.31	2.29	0.1676
150-180	30.0	7.32	2.31-2.34	2.32	0.1698
180-210	30.0	7.32	2.34-2.43	2.39	0.1750
210-240	30.0	7.32	2.43-2.57	2.50	0.1830
240-270	30.0	7.32	2.57-2.59	2.58	0.1889
270-300	30.0	7.32	2.59-2.70	2.65	0.1940
300-330	30.0	7.32	2.70-2.79	2.74	0.2006
330-360	30.0	7.32	2.79-2.84	2.82	0.2064
360-390	30.0	7.32	2.84-3.04	2.94	0.2152
390-411	21.0	5.12	3.04-3.08	3.06	0.1568
				Cumulative sound attenuation coefficient, α (3150 Hz) (dB/100m):	**2.49**

Table 3-3 Determination of the cumulative sound attenuation

AMC A2 2.2.2.2e
[Wind speed]

(1) Windspeed Limitations

The wind speed should be monitored against the specified wind speed limits. In cases when these limits are exceeded during an aircraft test run then that test run is invalid and might have to be repeated. No method has been approved for making data adjustments for wind speed or direction.

(2) Real-time Cross-Wind Component Measurements

Applicants are advised to provide approved real-time cross-wind component measurement systems such that the cross-wind component speeds can be verified after each aircraft test run. When the applicant uses a wind measurement system that is remotely located and not readily accessible, such as chart recorders that simultaneously and independently measure and record wind speed and direction, it may not be practical to determine the real-time crosswind component for each test run. For aeroplanes, if the applicant does not provide an acceptable real-time crosswind component measurement system, the 18 km/h (10 kt) maximum cross-wind component and the 13 km/h (7 kt) average cross-wind component become the maximum wind limitations regardless of wind direction.

GM A2 2.2.2.2f
[Anomalous meteorological conditions]

(1) Anomalous Winds

For aeroplanes, compliance of measured wind speeds with the requirements of 2.2.2.2e of Appendix 2 of the Annex may not be sufficient to ensure that the wind speeds at the aeroplane height or along the sound propagation path are not excessive. Such conditions may exist as a steady head, tail or cross wind, or as a wind from varying directions with increasing height. Anomalous winds may affect the handling characteristics of an aircraft during the noise duration. They also may affect the transmitted noise. Anomalous winds include not only gusts and turbulent winds, but also wind shear, strong vertical winds, and high crosswinds at the aircraft height and along the sound propagation path. An applicant may be required to measure winds aloft and provide the certificating authority with the information. Acceptability of the wind conditions over the propagation path will be determined by the certificating authority (see 2.2.2.2f of Appendix 2 of the Annex).

(2) Winds Aloft Measurement

Modern Inertial Navigation Systems (INS) and Differential Global Positioning Systems (DGPS) can provide on-board aircraft data that can be used to quantify winds aloft. The measurement of winds aloft can further be processed to provide a permanent record of wind speed and direction.

(3) Effects of Wind on Aeroplane Control

Certificating authorities have permitted a ± 20 per cent tolerance in overhead test height and a ± 10° lateral tolerance relative to the extended runway centre line. If the flight crew cannot fly within the pretest-approved flight path tolerance limits, or experiences major variations in airspeed or the aeroplane crabs or yaws significantly during the flight, adverse or anomalous wind conditions aloft are often the cause.

(4) Effects of Wind on Helicopter Control

If the test helicopter cannot be flown within the pre-test-approved flight path tolerance limits or experiences major variations in airspeed, or the aircraft yaws or sideslips excessively during the flight, adverse or anomalous wind conditions aloft are often the cause. Normally such issues only arise with gusty wind conditions, high crosswinds or in the presence of strong thermals.

AMC A2 2.2.2.2f
[Anomalous meteorological conditions]

(1) Flight Path

The flight crew should observe and record any occurrence where conditions aloft cause difficulty in maintaining the flight path or airspeeds, or when rough air in general makes the flight unacceptable.

In the context of determining whether such conditions are present for aeroplanes, 3.7.7 of Chapter 3 of the Annex specifies that "for take-off, lateral, and approach conditions, the variation in instantaneous indicated airspeed of the aeroplane must be maintained within ± 3 per cent of the average airspeed between the 10 dB-down points. This shall be determined by reference to the pilot's airspeed indicator. However, when the instantaneous indicated airspeed varies from the average airspeed over the 10 dB-down points by more than ± 5.5 km/h (± 3 kt), and this is judged by the certificating authority representative on the flight deck to be due to atmospheric turbulence, then the flight so affected shall be rejected for noise certification purposes."

(2) Applicant's Responsibility

When proposing a test site an applicant should consider that certain geographical areas are more susceptible to anomalous wind conditions than others. The applicant may only conduct certification testing when approved by the certificating authority.

GM A2 2.2.2.3
[Time of meteorological measurements]

(1) Upper Atmospheric Condition Measurements

Atmospheric conditions affect sound propagation. Therefore, measurements of temperature and relative humidity shall be made before and after each aircraft test run, at least one of which shall be made within 30 minutes of the test run. To avoid the possibility that the meteorological conditions might change significantly over time, both measurements shall be representative of the prevailing conditions during the test run. The measurements shall be made using an approved method at 10 m (33 ft) above the ground surface, and for aeroplanes only, from 10 m (33 ft) above the ground surface to the aeroplane test height at time of PNLTM. These measurements shall be obtained and validated throughout the test period to ensure acceptable meteorological data for the noise data evaluation process.

AMC A2 2.2.2.3
[Time of meteorological measurements]

(1) Atmospheric Measurements

Applicants should consider the maximum height that will be attained within the next 60 minutes, or less, of aeroplane test runs to ensure that adequate upper atmospheric measurements are acquired. Interpolations of atmospheric data for all test runs are made to the aeroplane height at the time of PNLTM. To have sufficient meteorological data to perform the interpolation to the actual time of each test run, the first meteorological measurement flight of the day should be made not earlier than 30 minutes before the first test run, and the last meteorological measurement flight of the day should be made not later than 30 minutes after the last test run flight of the day.

(2) Atmospheric Data Interpolation

The temperature and relative humidity data at the actual time of the test run shall be interpolated over time and height, as necessary, from the measured meteorological data. The interpolation time of the test run may be taken to be either the time the aircraft flew overhead or abeam the noise measurement point, or the time of PNLTM.

GM A2 2.2.2.6
[Aerodrome meteorological measurements]

(1) Aerodrome meteorological measurements

Wind speed, wind direction, cross-wind speed component, ambient temperature and ambient relative humidity should be determined throughout the test period using methods and measurement systems complying with the requirements of 2.2.2 of Appendix 2 of the Annex.

GM A2 2.3.1
[Aircraft position measurement]

(1) Aircraft Position Measurement

Several methods have been approved for measurement of aircraft position as described in 2.2.

(2) Independent Aircraft Position Determination

The certificating authority will approve only those aircraft position and height indicating and recording systems that are independent from the direct aircraft flight path indicating systems. The data from such independent systems should be recorded to produce a time coordinated permanent record of each test.

The independent system restriction does not prohibit use of real time flight guidance systems (e.g. Course Deviation Indicators (CDI) or Glide Slope Indicators (GDI)) on board the aircraft to assist the flight crew during noise certification tests. Systems such as microwave space position systems, INS, Precision DMU and DGPS can also provide guidance to the flight crew by providing the direct, real-time aircraft position relative to the extended runway centre line.

GM A2 2.3.2
[TSPI measurement system characteristics]

(1) Measurement System Synchronization

Approved aircraft position and height measurement systems shall be time synchronized with the noise and meteorological measurement systems. The time synchronization between noise measurements and aircraft position should be precise. A common time base should be used to synchronize noise, aircraft tracking and meteorological measurements (see GM A2 2.3.2 (3) for details).

Time-space-position information (TSPI) should be determined at intervals no greater than one-half second throughout the sound-measuring period (i.e. within 10 dB of PNLTM) by an approved method that is independent from systems installed aboard, and normally used to control, the aircraft. During processing, measured TSPI data shall be interpolated over time to the time of sound emission of each one- half second noise data record within the 10 dB-down period. The time associated with each one-half second record is 0.75 s before the end of each 2 s exponential averaging period (see 3.7.6 of Appendix 2 of the Annex).

Although the simplified procedure requires adjustment of only the (PNLT) maximum record to the reference track, emission coordinates should be determined for each one-half second record for use in background noise adjustment procedures and/or for determination of incidence-dependent free-field microphone and windscreen adjustments.

(2) Measurement System Component Approval

Some off-the-shelf TSPI equipment may require software enhancement to accommodate the specific installation. Each applicant should submit information to the certificating authority about the software used. The certificating authority will determine whether the software yields results that satisfy the Annex standards. All TSPI equipment and software should be demonstrated to, and approved by, the certificating authority to ensure the system's operational accuracy.

(3) Methods of Time Synchronization

Special care should be taken to properly synchronize noise data recordings with TSPI data (see 2.4 for details of specific methods).

GM A2 2.3.3
[Aircraft performance]

(1) Aircraft and Engine Performance Parameters

Examples of parameters needed for measurement of aircraft and engine performance include aircraft height, climb angle, airspeed and gross weight, flap position, landing gear position, engine thrust (power) setting parameters (e.g. compressor rotor speed, engine pressure ratio, exhaust gas temperature), and aircraft accessory condition (e.g. A/C and APU "on" or "off"). Any other parameters that may affect measurement or adjustment of noise data and/or aircraft or engine performance should also be recorded throughout the 10 dB-down period (e.g the status of surge bleed valves (SBV) and the centre of gravity (CG) position).

AMC A2 2.3.3
[Aircraft performance]

(1) Aircraft Performance Measurements

Calibrated instrumentation is required to determine aircraft performance. Adequate aircraft and engine parameters are to be recorded during all certification testing to ensure that aircraft performance can be accurately determined. For example, for transport aeroplanes this may necessitate measurement and recording of flap position, landing gear position, speed brake position, APU operation, and normal engine thrust (power) setting and associated flight parameters. Determination and recording of adequate information enables validation of the test configuration and adjustment of performance and engine performance from test conditions to reference conditions specified in 3.6 of Chapter 3 of the Annex.

(2) Recorder Sampling Rate

The measurements of aircraft position, airspeed, performance and engine performance parameters are to be recorded at an approved sampling rate sufficient to permit adjustments from test to reference conditions throughout the 10 dB-down period. An acceptable recording sampling rate for transport category aeroplanes is two to five samples per second.

3.1.2 Measurement of aircraft noise received on the ground

GM A2 3.2
[Environmental specifications]

(1) Measurement System Performance

The environmental conditions for specifying the performance of a measurement system are specified in 3.2 of Appendix 2 of the Annex.

GM A2 3.3.1
[Measurement system specifications]

(1) Measurement System Criteria

The specifications for a measurement system allow flexibility in the procurement of measurement system components by the applicant. While on-site EPNL analysis may be useful for estimation of recording levels or for other diagnostic purposes, a true acoustical analysis requires that data be recorded in the field. This will allow for later reanalysis or auditing of acoustical data. A recording also facilitates later off-line processing of acoustic data, including application of adjustments for items such as system frequency response, microphone pressure response, and analyzer bandwidth error. Recording simplifies synchronization with other pertinent data, such as tracking and meteorological measurements. Such synchronization is necessary for proper application of many of the required adjustments to noise data, such as adjustments for microphone free-field response, windscreen incidence-dependent insertion loss, the influence of ambient noise, high altitude jet noise effects, non-reference flight performance, and non-reference meteorological conditions.

(2) Approval of Measurement System

Certificating authority approval should be obtained for systems used for measurement, recording, and analysis of aircraft noise. Most of the currently available system components that are appropriate for aircraft noise certification use have already been approved, but implementations of new technology and variants or upgrades of existing components may require approval of the certificating authority. Of special concern is the potential for a digital component's functionality to change as a result of firmware or operating system upgrades or modifications. Applicants should be aware that approval of a particular component might be version-dependent.

AMC A2 3.3.1
[Measurement system specifications]

(1) Validation of Measurement System Configuration

Each applicant should submit information to the certificating authority about the measurement system and software used. The certificating authority will determine whether any listed components require approval.

(2) Changes in Measurement System Configuration

If an applicant makes changes to the approved measurement system configuration, the certificating authority should be notified before aircraft noise certification testing to determine whether additional evaluation and approval are required.

GM A2 3.4
[Windscreen insertion loss]

(1) Determination of Data Adjustments for Windscreen Insertion Loss

The physical condition of a windscreen can significantly affect its performance, and manufacturer-provided data for windscreen insertion loss are valid only for new or clean, dry windscreens. Insertion loss data adjustments for windscreens may be obtained by free-field calibration in an anechoic chamber.

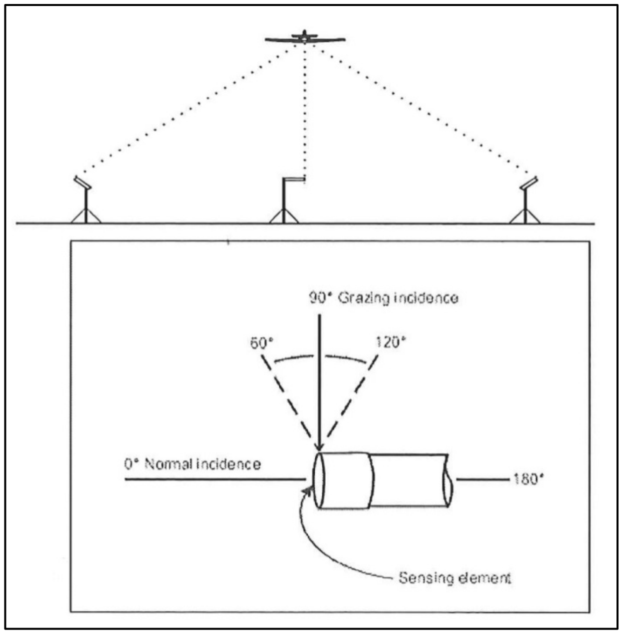


Figure 3-1 Illustration of sound incidence angles on a microphone

AMC A2 3.5.2
[Microphone orientation]

(1) Microphone Orientation

Figure 3-1 shows the orientations relative to a microphone sensing unit for grazing and normal incidence. For microphones located directly under the flight path, an orientation angle of 90º from vertical is appropriate regardless of target height. For noise measurements to the side of the flight path, applicants may wish to reorient the microphones for grazing incidence for each target height in order to maintain substantially grazing incidence throughout the 10 dB-down periods. In many cases, this reorientation can eliminate the need to apply data adjustments for varying-incidence, since the incidence angles will be more likely to be contained within ± 30º of grazing incidence. Figure 3-1 provides illustrations of microphones positioned for grazing incidence under the flight path and to the side of the flight path of an aeroplane.

GM A2 3.5.4

[Microphone specifications]

(1) Microphone Specifications

Table A2-1 of Appendix 2 of the Annex specifies the maximum permitted differences between the free-field sensitivity of a microphone at normal incidence and the free-field sensitivity at specified sound incidence angles for sinusoidal sound waves at each one-third octave band nominal midband frequency over the range of 50 Hz to 10 kHz. These differences are larger at higher frequencies, allowing for the effect of the microphone body in a free-field environment.

(2) Microphone Characteristics

The specifications of Table A2-1 of Appendix 2 of the Annex are based on the performance characteristics of typical one-half inch condenser microphones designed for nearly uniform frequency response at grazing incidence (see Figure 3-1). Other microphones may be used, provided they meet the specified performance requirements. For example, pre-polarized (i.e. electret condenser) free-field microphones greatly minimize the possibility of arcing in humid environments and do not require an external polarization voltage. Although many of these microphones are intended primarily for use in normal-incidence free-field applications, they can be used in aircraft noise certification testing if their performance at grazing incidence meets the requirements of 3.5 of Appendix 2 of the Annex.

GM A2 3.6.1
[Recorder specifications]

(1) Recorder Types

An applicant has a choice of recorder types that will satisfy the requirement for recording "the complete acoustic signal" during certification testing. In addition to a magnetic tape recorder, other means of attaining a "true" acoustic recording include digital audiotape (DAT), recordable compact disc (CD-R), and direct-to-hard-disk recording. The applicant should be aware that systems that use data compression techniques that result in substantial data loss, such as Mini-Disc (MD) or digital compact cassette (DCC), are not acceptable.

AMC A2 3.6.1
[Recorder specifications]

(1) Frequency Range for Recordings

The time-varying waveform produced by the microphone response to noise signals during certification tests should be recorded. If there are questions about the data observed during the tests, the recording can be replayed, multiple times if necessary, to verify the results. Recorded data, whether digital or analog in nature, should allow reproduction and reprocessing of an analog signal over the frequency range of 40 Hz to 12.6 kHz. A dynamic range of at least 60 dB is recommended.

Many typical instrumentation DAT recorders feature a nominal 10 kHz bandwidth operating mode in which the attenuating response of the anti-aliasing filter intrudes within the 10 kHz one-third octave passband. In such cases, the recorder should be operated in a nominal 20 kHz-bandwidth mode, which may reduce the number of available channels or the duration of available time per tape.

Note.- Although the one-third octave bands of interest are those with nominal center frequencies of 50 Hz through 10 kHz, to ensure that the entire actual bandwidth of the uppermost and lowermost bands is included, the center frequencies of the one-third-octave bands immediately outside this range are specified.

(2) Digital Recording Levels

The overload characteristic of a digital system is determined primarily by the limits of the analog-to-digital-conversion. Since such an overload condition is characterized by an abrupt, catastrophic type of distortion, the level range should be set so that the anticipated maximum signal level is at least 10 dB, and preferably 20 dB, below the upper boundary of the linear operating range.

(3) Dynamic Range Limits for Digital Recorders

The lower limit of a digital recording system's usable dynamic range is more often determined by amplitude non-linearity due to "quantization error", rather than by the presence of a noise floor. Digital devices such as recorders or analyzers that are to be used for aircraft noise certification purposes should be tested to determine the extent of such non-linearity.

(4) 16-Bit Quantization Systems

The theoretical dynamic range of such a system is usually assumed to be near 96 dB (i.e. $20 \times \log_{10}(2^{16})$). At the lower limit of this range, there is a potential for a 6 dB error in the digitized signal versus the analog input signal that it represents. Reference 8 imposes a ± 0.4 dB limit on acceptable linearity error in the reference level range and ± 0.5 dB for a linear operating range of at least 50 dB. As amplitude levels are increased above the lower quantization limit the linearity error is reduced. If the guidance for setting the level range is followed the usable dynamic range is further decreased. Significant improvement of amplitude linearity can be obtained via the implementation of techniques such as over-sampling and dithering. Therefore, testing shall be performed to determine the actual limits for each digital recording system. Note that assumptions based on experience with analog systems do not always apply.

AMC A2 3.6.2
[Pre-emphasis]

(1) Pre-emphasis Systems

Use of pre-emphasis will only be allowed if the system also employs complementary de-emphasis. Attempts to compensate for the effects of a pre-emphasis filter by applying one-third octave band de-emphasis adjustments, either numerically to analyzed data via a pink noise adjustment or on a band-by-band basis using separate gain stages for each one-third-octave band filter, are not allowed. In addition, use of a pre-emphasis/de-emphasis system will require testing and documentation of all filters and gain stages involved to ensure that any errors are quantified and minimized, and that the system performs predictably and reliably.

AMC A2 3.6.9
[Attenuator specifications]

(1) Attenuator Specification

The specification allows for the use of switchable voltage input range settings, now commonplace on DAT recorders, as controllable attenuation steps for gain-setting purposes. In all cases, attenuators should have fixed repeatable steps. Any devices in the measurement system that use vernier or continuously–adjustable gain controls should also have some demonstrable means of being fixed, or locked at a specific setting to eliminate non-traceable gain errors.

GM A2 3.7.2
[Linear integrating analyzer specifications]

(1) Externally Controlled Linear-Integrating Analyzers

In cases where a computer or other external device is used to control and/or communicate with an analyzer performing linear integration, extra care should be taken to ensure that the integration period requirements are met. Some analyzers from major manufacturers have required a factory modification in order to provide an integration time within 5 ms of the specified 500 ms integration period.

GM A2 3.7.3
[Analyzer performance specifications]

(1) Analyzer Specifications

Reference 9 specifies the electrical performance requirements of one-third octave band filters, including tolerances for the attenuation in the transition bands (i.e. “skirts”) adjacent to the one-third octave pass-bands. Most digital one-third octave-band analysis systems offer only hardwired filtering algorithms that emulate the response of a traditional third-order analysis filter having a maximally-flat pass-band. However, some analysis systems allow the selection of other filtering algorithms which might not provide equivalent performance. Applicants should demonstrate the effects that alternate filter design response characteristics might have on noise certification EPNL values.

(2) Determination of Bandwidth Error Adjustments

The manufacturer can establish the geometric centre frequencies of one-third octave band filters using either Base 2 or Base 10 systems. While the use of either method results in frequencies close to the nominal centre frequencies referred to in Table A2-3 of Appendix 2 of the Annex it is important to note which system is used so that the bandwidth error adjustment can be properly determined. Use of test frequencies calculated by a different base-number system than that for which the analyzer was designed can result in erroneous values for these adjustments.

AMC A2 3.9.3
[Microphone incidence adjustments]

(1) Applications of Adjustments for Incidence

When using microphones whose frequency response is nearly flat at grazing incidence, and when the angles of incidence of sound emitted from the aircraft are within ± 30° of grazing incidence, a single set of data adjustments for free-field response and windscreen insertion loss, based on grazing incidence, is considered sufficient to account for incidence effects. When it is impractical to orient the microphone properly to maintain grazing incidence, provided that a continuous record of TSPI is available, free-field and windscreen insertion-loss incidence data adjustments can be applied to the noise data on a spectral-record-by-spectral-record basis. These adjustments are obtained by calculating the angle of incidence for each record, using the point of time which characterizes the 2-second averaging period (see 3.7.6 of Appendix 2 of the Annex) and determining the aircraft's emission coordinates and angle of incidence for the sound measured at that time.

GM A2 3.9.4
[Pink noise specifications]

(1) Pink Noise

Pink noise contains equal energy in each octave band or fractional octave band (e.g. the octave from 100 Hz to 200 Hz contains the same amount of energy as the octave from 1 kHz to 2 kHz, although for the lower-frequency octave, it is distributed over a frequency range 10 times narrower).

(2) Pink Noise Usage

Because of the dynamic nature of the pink noise signal longer samples produce statistically better measurements. A minimum durations of 30 s of pink noise should be recorded.

AMC A2 3.9.5
[Measurement system field calibration]

(1) Measurement System Field Calibration (All components of the measurement system except microphones)

All components of the measurement system, except microphones, should be tested while deployed in the field using pink noise at a level within 5 dB of the calibration level (see 3.9.5 of Appendix 2 of the Annex). The signal should be recorded for a duration of at least 30 s so that one-third octave band system frequency response adjustments can be determined and applied during analysis. The pink noise generator should be calibrated within 6 months of the measurement, and is acceptable for certification use only if its output in each one-third octave band does not change by more than 0.2 dB between calibrations.

GM A2 3.9.7
[Acoustic calibrator adjustments]

(1) Acoustic Calibrator Output Adjustments

Acoustic calibrator outputs may require adjustment for ambient conditions such as temperature and atmospheric pressure, coupler volume etc. (see 3.9.7 of Appendix 2 of the Annex). All such adjustments should be applied in the data processing stage rather than by using an adjusted calibration value in the analyzer. In this way, a traceable record of the adjustments can be maintained.

(2) Calibration Traceability

All performance calibration analyses of calibration equipment should be traceable to a national standards laboratory as determined by the certificating authority.

AMC A2 3.9.8
[Field acoustical calibrations]

(1) Field Acoustical Calibrations

At the start and end of each measurement day, at the beginning of each physical recording (i.e. each tape reel, cartridge, cassette, disk etc.), and at the end of the last physical recording, an acoustic calibration signal of known amplitude and frequency should be fed through the entire measurement system, including microphone, as deployed in the field, and recorded. All components of the system, excluding the windscreen, should be in place at this time, including cables, attenuators, gain and signal-conditioning amplifiers, filters (including pre-emphasis) and power supplies. During calibration, attenuators and gain stages should be set to prevent overload, and to maintain the calibration signal level on the reference level range within the limits specified in 3.6.6 of Appendix 2 of the Annex. If any switchable filters that could affect the calibration signal are utilized during measurements, then calibrations should be performed both with and without these filters enabled. Components of the electrical system should not be added, removed, or replaced without re-calibrating the entire system immediately before and after each change.

AMC A2 3.9.10
[Windscreen loss adjustments]

(1) Determination of Windscreen Data Adjustments

The physical condition of a windscreen can significantly affect its performance, and manufacturer-provided windscreen data adjustments for insertion loss are only valid for new, or clean, dry windscreens. For these adjustments, a single set of values based upon wind screen insertion loss tests at grazing incidence may be used when the angles of incidence of sound emitted from an aircraft are within +30° of grazing incidence. For other cases, the windscreen insertion loss adjustments should be determined and applied on the basis of intervals between angles tested not exceeding 30°.

When the windscreen data adjustments provided by the manufacturer are presented in the form of curves, care should be taken to include the insertion loss throughout each one-third octave band, rather than just at the nominal midband frequency. Windscreen insertion loss can vary substantially within the frequency range of a single band and shall be averaged or faired to more accurately correct one-third-octave band data for the presence of the windscreen. Windscreen data adjustments may also be obtained by free-field calibration in an anechoic chamber.

AMC A2 3.10.1
[Measurement system background noise]

(1) Measurement System Noise

Since measurement system noise can add energy to measured aircraft noise levels, the background noise measurement described in 3.10.1 of Appendix 2 of the Annex should be made with all gain stages and attenuators set as they would be used during the aircraft noise certification measurements. If it is expected that multiple settings will be required during the measurements, background noise data should be collected at each of these settings. Care should be taken to ensure that the background noise is truly representative of that present during the aircraft noise certification tests

(2) Mean Background Noise Assessments

At least 30 s, of background noise data shall be time-averaged to determine the mean level for each one-third octave band. The PNL value for this averaged spectrum should then be calculated using the procedures defined in 4.1.3a of Appendix 2 of the Annex. The aircraft noise level data should also be analyzed, and PNL values calculated for each spectral record. The maximum aircraft PNL value should be at least 20 dB above the PNL of the averaged background noise spectrum for the data to be considered acceptable.

3.1.3 Calculation of effective perceived noise level from measured data

GM A2 4.2
[Instantaneous sound pressure levels]

(1) "Instantaneous" Sound Pressure Levels

For the purposes of this procedure, "instantaneous" sound pressure levels are considered to be one-third octave band sound pressure levels for each one-half second record obtained using a continuous exponential averaging process as described in 3.7.5 of Appendix 2 of the Annex, or its equivalent.

AMC A2 4.3.1
[Tone correction calculation]

(1) Data Precision for Tone Correction Computation

Prior to Step 1, it is recommended that all one-third-octave band sound pressure levels be temporarily rounded to 0.1 dB resolution. The tone correction procedure presented here includes several steps that utilize decibel level criteria to characterize the significance of tonal content. These criteria can become artificially sensitive to small variations in level if resolution finer than 0.1 dB is used in the computations

AMC A2 4.3.1 (STEPS 4, 5)
[Adjustments relating to background noise]

(1) Data Adjustments for Background Noise

When the Technical Procedure presented in 2.6.3.2 is used for adjustment for the effects of background noise, Steps 4 and 5 of this tone correction procedure should be modified as follows:

– Step 4 - The "Last Good Band" (LGB) should be used in place of the highest-frequency band (i=24); and

– Step 5 - A new slope, s'(25,k), should be calculated for the band beyond LGB as described for an imaginary 25-th band. This slope should be used in place of the slope derived from the actual level of the band beyond LGB.

AMC A2 4.3.1 (STEP 10)
[Data resolution after tone correct in calculation]

(1) Data Precision (After Calculation of Tone Correction Factor)

At this point, the original sound pressure level resolution of 0.01 dB should be restored. Although the required precision of reported EPNL is 0.1 dB, all other intermediate calculations external to the tone correction process should maintain a precision of at least 0.01 dB.

(2) Identification of Pseudotones

Section 3.3.2.2 presents guidance material on methods for identifying pseudotones. Note that the use of ground plane or 10-metre (33 ft) microphones is supplemental to the required 1.2-metre (4 ft) microphones, and is allowed only for identification of frequency bands within which pseudotones might occur, and not for the determination of aircraft noise certification levels.

(3) Tone Correction Factor Adjustment

When tone correction factors result from false or fictitious tones, recalculation is allowed using revised sound pressure level values, based on narrow-band analysis, of the smoothed spectral levels obtained in Step 7. Once the levels have been revised, the tone correction factor should be recomputed for the revised one-third octave band spectrum. This recomputed maximum tone correction factor should be applied, even if it occurs at or near the band associated with an artificial tone, and approval of the certificating authority should be obtained for the methodology used.

GM A2 4.4.2
[Band sharing adjustment]

(1) Band Sharing Adjustment Concept

The one-third octave band filtering process specified for analysis of aircraft noise certification data in 4.3.2 of Appendix 2 of the Annex may allow the tone correction procedure to under-predict a tone correction factor when the frequency of a tone is located at or near the edge of one or more one-third-octave bands. To account for this phenomenon, a band sharing adjustment is computed that takes advantage of the fact that, as a result of the Doppler Effect, a tone that is suppressed at PNLTM will probably appear normally in the spectra that occur before or after PNLTM. By averaging the tone correction factors calculated for the spectra within a 2 s period around PNLTM, the tone correction factor that would have occurred at PNLTM if it were not suppressed can be reasonably estimated.

AMC A2 4.4.2
[Calculation of band sharing adjustment]

(1) Computation of Band Sharing Adjustment

Although the Annex refers to identification of the frequency bands in which maximum tone corrections occur for the records near PNLTM, the presence or absence of band sharing cannot be established merely by observing these frequencies. Even though the maximum tone that occurs in a one-third octave band spectrum may not be related to the band of maximum tone correction in the PNLTM spectrum, a related tone may still be present. Therefore, the average of the tone corrections of all spectra within 1 s (i.e. five one-half second data records) of PNLTM should be used regardless of the bands in which maximum tones are found. If the band sharing adjustment is believed to result from effects other than band sharing, the applicant should demonstrate its absence for each event.

(2) Adjustment of PNLTM for Band Sharing

The band sharing adjustment should be computed before the determination of the 10 dB-down period and should be included in the reported PNLTM and EPNL values for the test condition data.

(3) Application of Band Sharing Adjustment for Simplified Procedure

When the simplified procedure is used to adjust data to reference conditions, the band sharing adjustment, should be applied to the $PNLT_r$ at time of PNLTM before "Δ_1" and $EPNL_r$ is calculated.

(4) Application of Band Sharing Adjustment for Integrated Procedure

When the integrated procedure is used to adjust data to reference conditions, a new band sharing adjustment should be calculated as in 4.4.2 of Appendix 2 of the Annex. This new band sharing adjustment uses the average of the tone correction factors of the $PNLTM_r$ spectrum and the two preceeding and two succeeding spectra after adjusting them to reference conditions, and should be applied to the $PNLTM_r$ value prior to identification of the reference condition 10 dB-down points and calculation of $EPNL_r$.

GM A2 4.5.4
[Equations for computing duration correction factor]

(1) Duration Correction Factor

The equation for the duration correction factor, D, in 4.5.4 of Appendix 2 of the Annex is valid only for records of one-half second in length. The constant value 13 is used to normalize the one-half second values to the 10 s standard duration (i.e. 10 s duration compriseing twenty 0.5 s data records and $10 \times \log_{10} 20 = 13.01$).

AMC A2 4.5
[Noise duration]

(1) Noise Duration (10 dB-down Period)

This period is the portion of the aircraft flyover in which the measured noise level is within 10 dB of PNLTM (i.e. the period to be used for the calculation of EPNL). To ensure an adequate duration of recorded noise, recording systems should be activated, and the aircraft maintaining a stable condition, when the noise level at the first microphone location is estimated to be approximately 20 dB(A) below what is expected to be L_{Amax}. Care should be taken during use of the flight path intercept method (see 3.2.1.1.1) to ensure that noise levels have fallen 20 dB(A) below L_{Amax} before flight path go-around procedures are initiated.

Note.- If recorded data do not encompass the entire 10 dB-down period, an EPNL cannot be calculated from those data, and the event should not be used for aircraft noise certification purposes.

(2) Identification of the First and Last Records within the Noise Duration

When identifying the records that define the limits of the noise duration, those records having PNLT values closest to the actual value of PNLTM-10 dB should be used. As a result, the PNLT values for the PNLTM-10 dB points may not always be greater than or equal to PNLTM-10 dB.

In order to illustrate the correct identification of the 10 dB-down points Figure 3-2 provides examples of PNLT time-histories made up of records calculated from measured one-half second values of SPL in accordance with the procedures specified in 4.2 of Appendix 2. The shaded record k_M represents the record associated with PNLTM. Shaded records k_F and k_L represent respectively the first and last 10 dB-down points.

In the first example the PNLT value associated with k_F is greater than PNLTM-10. The PNLT value associate with k_L is less than PNLTM-10.

In the second example there are two records after k_M with a value equal to PNLTM-10. In this case k_L is the last of the two records. The first 10 dB-down point k_F is the record closest in value to PNLTM-10, ignoring any records that precede it with greater values but which are less in value than PNLTM-10.

Note.- In all cases in the calculation of EPNL the contribution of all the records from k_F to k_L inclusive should be included.

3.1.4 Reporting of data to the certification authority

GM A2 5.1
[Compliance records]

(1) Compliance Records

For compliance with section 5 of Appendix 2 of the Annex all data measured during noise certification testing, including time histories of physical measurements, noise recordings, instrument calibrations etc., are to be recorded in permanent form and made available to the certificating authority for review, inspection and approval. A common procedure is for the applicant to submit representative samples of test data for each noise measurement point and adjustments to measured data to permit the certificating authority to determine compliance with the Annex. The applicant may either submit the complete test records along with the required data adjustments, or when approved by the certificating authority, the applicant may instead submit samples of test data along with the required data adjustments.

GM A2 5.4
[$EPNL_r$ average values]

(1) Average $EPNL_r$ Levels when using the NPD Equivalent Procedure

For aeroplanes the average value of $EPNL_r$ from an NPD database (see 3.2.1.1.2.1) is the noise level determined along the regression line through the adjusted data set at the appropriate thrust (power) and distance values, including any other additional adjustments necessary (e.g. adjustment to the aircraft reference speed).

(2) Single Test Values

When more than one noise measurement system is used at any one noise measurement point, the resulting noise level is to be the average of the measured noise levels for each noise measurement point. This requirement does not apply to noise levels measured by microphones not required for acquisition of noise certification data.

(3) Valid Conditions

All valid noise measurements are to be included in the confidence interval calculations even when they produce results that are outside the 90 per cent confidence limit of ± 1.5 dB. The cause of erratic or possibly invalid noise data may include testing under different temperature and humidity extremes, anomalous winds aloft, changes in noise measurement system components, changes in aircraft hardware, background noise, shift in instrument calibrations, or not testing in accordance with the approved test plan etc. The certificating authority is to make a determination, during the course of noise certification testing, as to the validity of all noise measurements. A noise measurement may not be excluded from the confidence interval calculations at a later date without certificating authority approval. Noise measurements determined in the field to be invalid for any reason may need to be repeated in order to achieve the required minimum number of valid test runs.

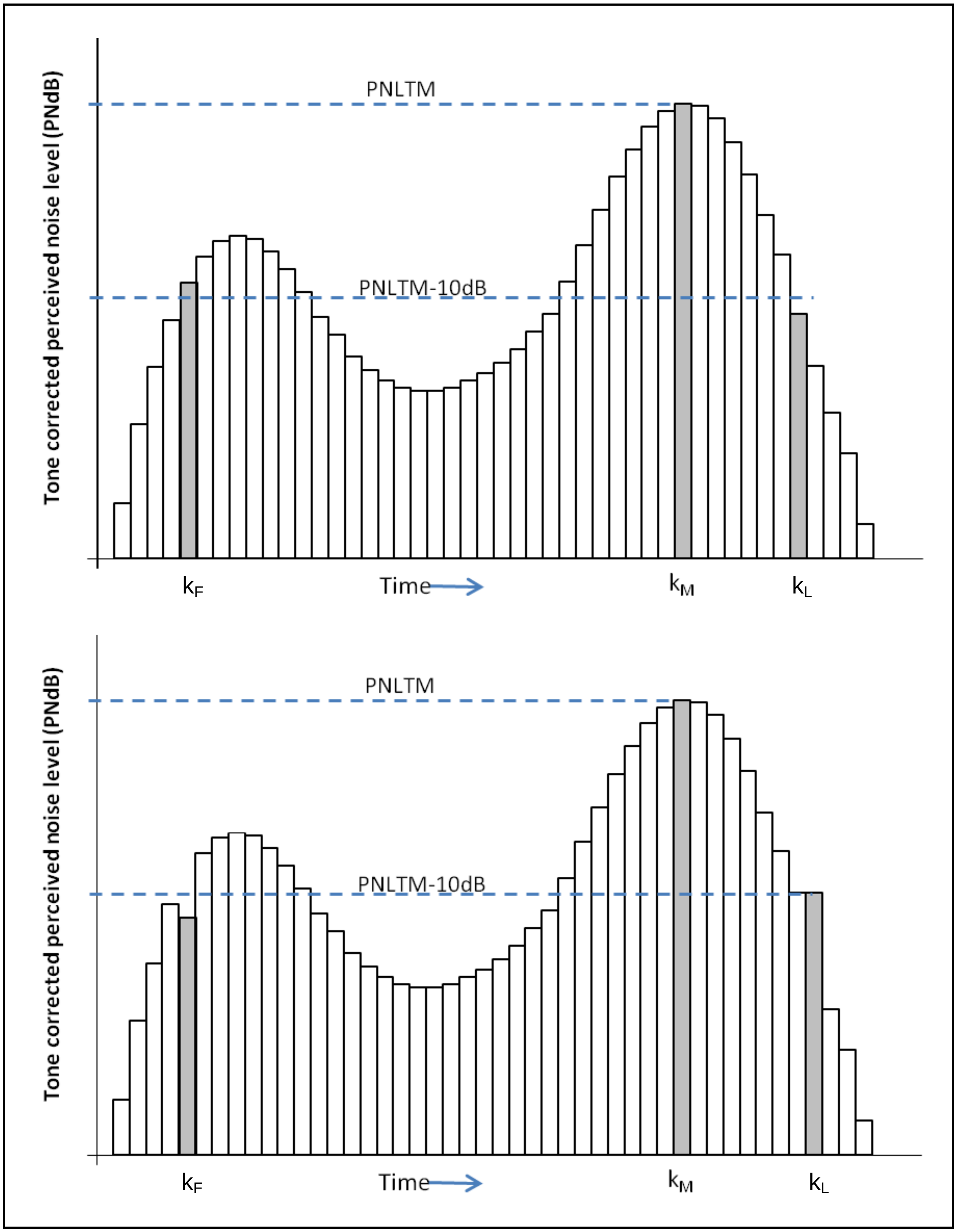


Figure 3-2 Illustrated example of identification of first and last 10 dB-down records

AMC A2 5.4
[Calculation of 90 per cent confidence intervals]

(1) Methods for Calculating 90 Per Cent Confidence Interval

Section 2.5 provides confidence interval calculation methods for: clustered measurements, regression mean line, static test derived NPD curves, and analytically derived NPD curves, along with worked examples. Calculation methods for determining 90 per cent confidence interval values for clustered and pooled datasets are presented in 2.5.6.2 and 2.5.6.5.

(2) Retest Requirements

The certificating authority may require an applicant to retest or provide additional test data for any of the three noise measurement points when the reported results indicate:

a) a required measurement is reported to be invalid; or

b) an insufficient number of measurements were conducted by the applicant to determine a suitable data sample; or

c) data scatter indicates that the data are not from a normal population or trend (e.g. a discontinuity due to low power SBV operation); or

d) the 90 percent confidence interval for a noise measuring condition exceeds the allowable ± 1.5 dB; or

e) the test was not conducted in accordance with an approved noise certification compliance demonstration plan.

3.1.5 Nomenclature: Symbols and units
(reserved)

3.1.6 Sound attenuation in air
(reserved)

3.1.7 Adjustment of helicopter flight test results

The objective of a noise certification test is to acquire data for establishing an accurate and reliable definition of a helicopter's noise characteristics. Section 8.7 of Chapter 8 of the Annex establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

GM No. 1 A2 8.1.1
[Adjustments to reference conditions]

(1) Adjustments to Reference Conditions

Most noise certification tests are conducted during conditions other than the reference conditions. This includes differences in height, lateral position, airspeed, rotor speed, temperature and relative humidity. Therefore, measured noise data should be adjusted to reference conditions to determine whether compliance with certification noise limits of Chapter 8 of the Annex may be achieved. Both positive and negative adjustments must be applied for the differences between the test and reference conditions. Adjustment procedures and analysis methods should be reviewed and approved by the certificating authority. The certificating authority should ensure that data adjustment and analysis methods that are proposed by applicants satisfy requirements of the Annex and approved procedures. Any changes, including software revisions, firmware upgrades, or instrumentation changes are subject to certificating authority review before they can be used for noise certification evaluations. Program validation should be planned and the required information submitted to the certificating authority early in the certification cycle, since the time required for evaluation and approval may vary dependent upon the issues encountered.

(2) Non-Positive SPLs

Whenever non-positive one-third octave band aircraft noise levels are obtained, whether as part of the original one-third octave band analysis, or as a result of adjustments for background noise or other approved procedures, their values should be included in all relevant calculations. The practice of "Band-Dropping", where masked levels are methodically set equal to zero , is not considered to be an acceptable substitute for reconstruction of masked levels per the background noise adjustment guidance provided in 2.6. For any aircraft noise spectrum subject to adjustment to reference conditions, all one-third octave bands, including those containing masked levels or reconstructed levels, including values less than or equal to zero dB, should be adjusted for differences between test and reference conditions.

(3) Direction of Flight Considerations

Since overflights are made in two directions with headwind and tailwind components, the lateral (sideline) microphones will be either "left sideline" or "right sideline" depending on the direction of flight. Hence sideline overflight data need to be sorted by left microphone and right microphone for data adjustments and reporting. Note that sorting by left and right sideline microphone is also appropriate for take-off and approach if more than one direction of flight is used.

It should also be noted that an equal number of overflight test runs with headwind and tailwind components are required. If after analysis the applicant finds that there is at least the required minimum of three measured values in each flight direction, but there are more in one direction than in the other, the applicant then will need approval of the certificating authority as to which are to be used in the determination of the final EPNL value for overflight.

GM No. 2 A2 8.1.1
[Reference data sources]

(1) Manufacturer's Data

Adjustment of noise values from test to reference conditions should be based on approved manufacturer's data.

Manufacturer's data should include:

a) Reference flight profiles;

b) Take-off and overflight engine power settings at reference conditions; and

c) Reference airspeeds.

GM A2 8.1.2
[Adjustments to measured noise data]

(1) Reference Flight Path Noise Propagation Angle

In calculating the position of the PNLTM on the reference flight path, the emission (i.e. noise propagation) angle (θ) relative to the flight test path must be kept the same as for the test flight path. The elevation angle (ψ) relative to the ground plane is not constrained, and determination and reporting of this angle is required.

(2) Maximum Adjustments

To prevent excessive adjustments to the measured data, the summation of all the adjustments for differences between the test flight path and the reference flight path for overflight and approach is limited to 2 EPNdB. For take-off the summation of the adjustments is limited to 4 EPNdB of which the sum of Δ_1 and the -7.5 log term from Δ_2 must not exceed 2 EPNdB. The additional allowance for take-off acknowledges that larger differences between the test flight path and reference flight path can occur for this condition as a result of the influence of wind speed on the test flight path. It is recommended, however, that the applicant note that methods discussed in AMC A2 8.2.1 can be used to minimize this difference for take-off.

GM A2 8.2.1
[Take-off profile]

(1) Reference Take-Off Profile

Figure 3-3 illustrates the reference take-off profile and an idealized test or measured take-off profile under zero wind conditions.

The reference take-off profile is a straight line segment. It starts from a defined point C_r that is 500 m (1640 ft) from the center microphone location A and at a height of 20 m (65 ft) above the ground. The reference climb angle (β) of the straight line path will depend on the certificated best rate of climb and V_y at the reference conditions. The reference profile ends at a point I_r which will encompass the 10 dB-down period of the noise measurements.

Note.- For clarity the location of the test and reference PNLTM points, L and L_r, are illustrated at the same position in relation to both the centre line noise measurement point A and the starboard lateral (sideline) noise measurement point S. Normally however L, and hence L_r, will be a different position on the test and reference flight paths for each noise measurement point.

(2) Reference Climb Angle

The reference climb angle, β, is based on the best rate of climb and V_y airspeed determined from approved manufacturer's data for the take-off performance of the helicopter at the reference conditions. Since airspeed is defined as being in the direction of the flight path, the climb angle β is the arcsine of the ratio of best rate of climb to V_y. On a helicopter that is engine power limited at the reference conditions, the best rate-of-climb has to be calculated from the minimum specification engine(s) performance. On many helicopters the take-off characteristics will be dependent on gearbox torque limit and this will be typically less than the torque associated with minimum specification engine(s) at the reference conditions. Since all procedures have to be consistent with the airworthiness regulations, the gearbox take-off torque limit should be used to calculate the applicable best rate of climb at the maximum noise certification mass for those helicopters that are performance limited by the gearbox characteristics at the reference conditions.

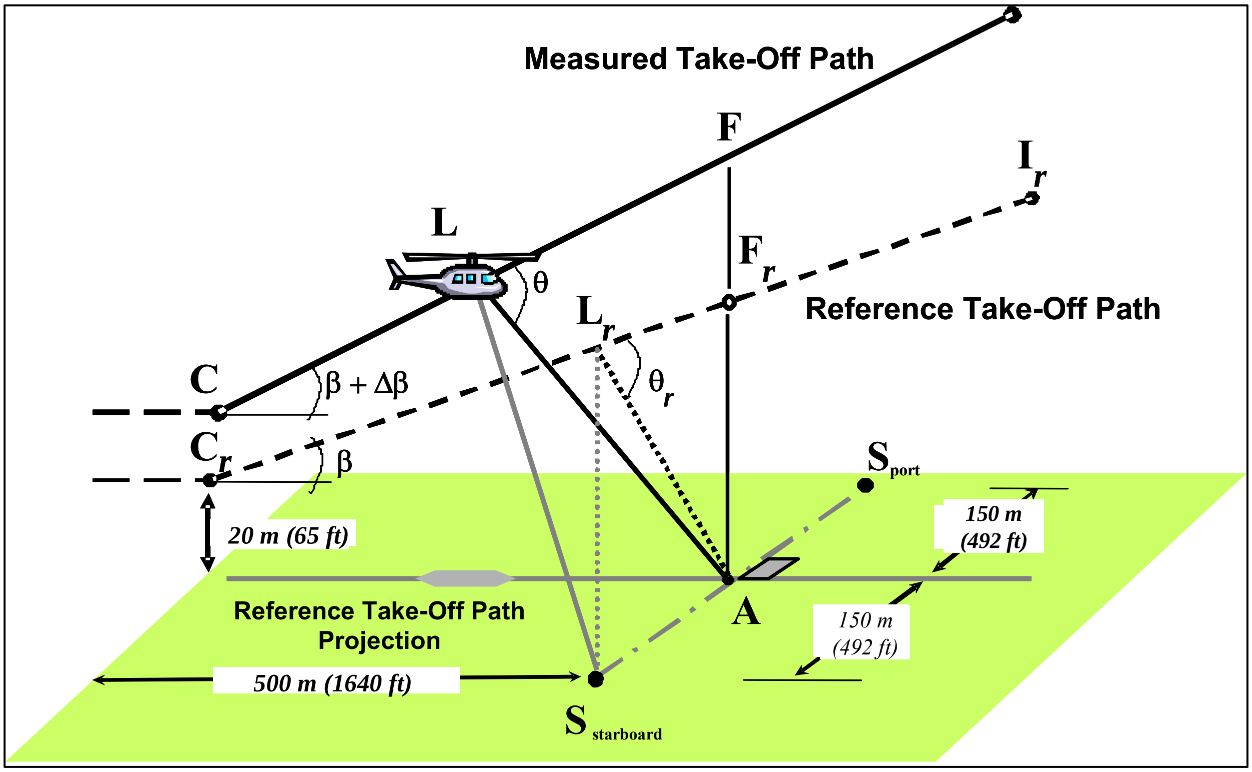


Figure 3-3 Comparison of measured and reference take-off profiles

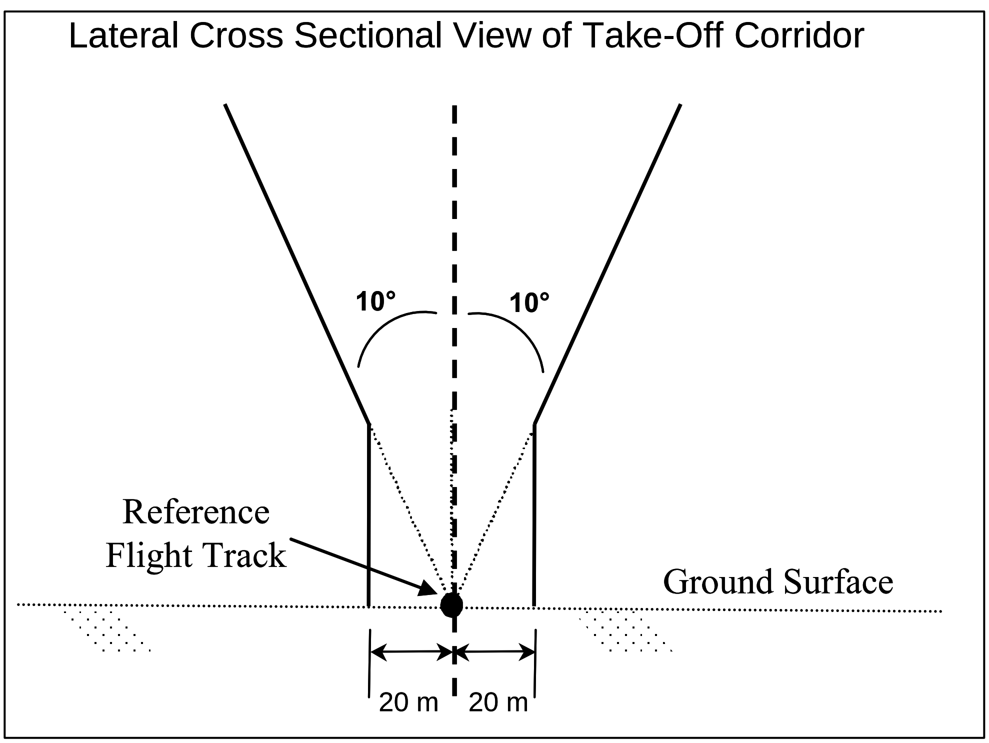


Figure 3-4 Lateral deviation tolerances for take-off

AMC No. 1 A2 8.2.1
[Take-off test conditions]

(1) Take-Off Requirements

The take-off profile is commenced from a level flight at a height of 20 m (65 ft). After reaching position C, take-off power has to be applied to initiate the climb. The take-off power will either be dependent on the gearbox torque limit for take-off or minimum installed engine(s) take-off power torque at the reference conditions at Sea Level and 25°C (77ºF).

(2) Test Airspeed

The best rate-of-climb airspeed V_y to be used is that determined from the take-off performance at Sea Level and 25°C (77°F) during airworthiness certification. This is to be maintained during the complete take-off procedure. To account for test-to-test variation and slight variations during each test run, a tolerance of ± 9 km/h (± 5 kt) is allowed.

(3) Rotor Speed

The mean value of the rotor speed during the 10 dB-down period is to be within ± 1 per cent of the maximum normal operating rotor speed value at the reference take-off condition.

(4) Flight Path Deviations

To minimize lateral flight path deviations, and hence the difference in noise levels due to off-track position at the PNLTM emission point, the helicopter must fly over the reference flight track during the 10 dB-down period within ± 10° or ± 20 m (± 65 ft) from the vertical, whichever is the greater. This is illustrated in Figure 3-4. There is no direct height limitation but the adjustments that take into account differences between the reference and test sound propagation distances at PNLTM are limited to 2 EPNdB as discussed in GM A2 8.1.2 (2).

(5) Helicopter Test Mass

The mass of the helicopter during the noise certification demonstration (see 8.7.11 of Chapter 8 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the take-off demonstration. No adjustment of the noise data to maximum take-off mass is required. At least one take-off test run must be completed at or above this maximum certificated take-off mass. If the value of the maximum take-off mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the Rotorcraft Flight Manual.

AMC No. 2 A2 8.2.1
[Take-off flight test procedures]

(1) Test Take-Off Profile

The test take-off profile requires stabilized flight conditions only over the 10 dB-down period in the climb portion of the procedure.

(2) Number of Test Runs

At least six test runs are required with simultaneous noise measurements at each of the noise measurement points. It should also be remembered that synchronized noise and flight path data is required. Since it cannot be determined if each test run meets all the requirements of Chapter 8 of the Annex until the analysis is partly completed, the applicant will find considerable merit in conducting additional take-off test runs. Experience suggests that 8 to 10 test runs would normally provide adequate safeguard against some test runs being determined invalid during subsequent analysis. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process.

(3) Flight Airspeed Tolerance

A ± 9 km/h (± 5 kt) tolerance about the reference airspeed is specified in 8.7.6 of Chapter 8 of the Annex. This is not intended to allow tests at different speeds but rather to account for variations during the 10 dB-down period which occur during an individual test run as a result of the pilot attempting to maintain the other take-off requirements and test-to-test variations.

The value of V_y is published in the take-off performance section of the Rotorcraft Flight Manual and is typically defined as an indicated airspeed (IAS). The applicant should note the reference airspeed is the true airspeed (TAS). Since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and meteorological conditions should be used to convert between TAS and IAS.

(4) Horizontal Adjustment of Climb Initiation

Position C in Figure 3.3 may be varied, subject to approval by the certificating authority, to minimize the difference between the test and reference heights vertically above the flight track noise measurement point. This difference can result from the effect of wind on the climb angle during testing (Figure 3.5 illustrates the case of a headwind). Note that even for zero or very low wind, the transition from the horizontal flight to the climb can take a significant time. This will be the case normally on larger and heavier helicopters. The resulting flight path could be well below the reference profile. In this case there would be merit in moving the Position C further away from the noise measurement point. This is illustrated in Figure 3.6.

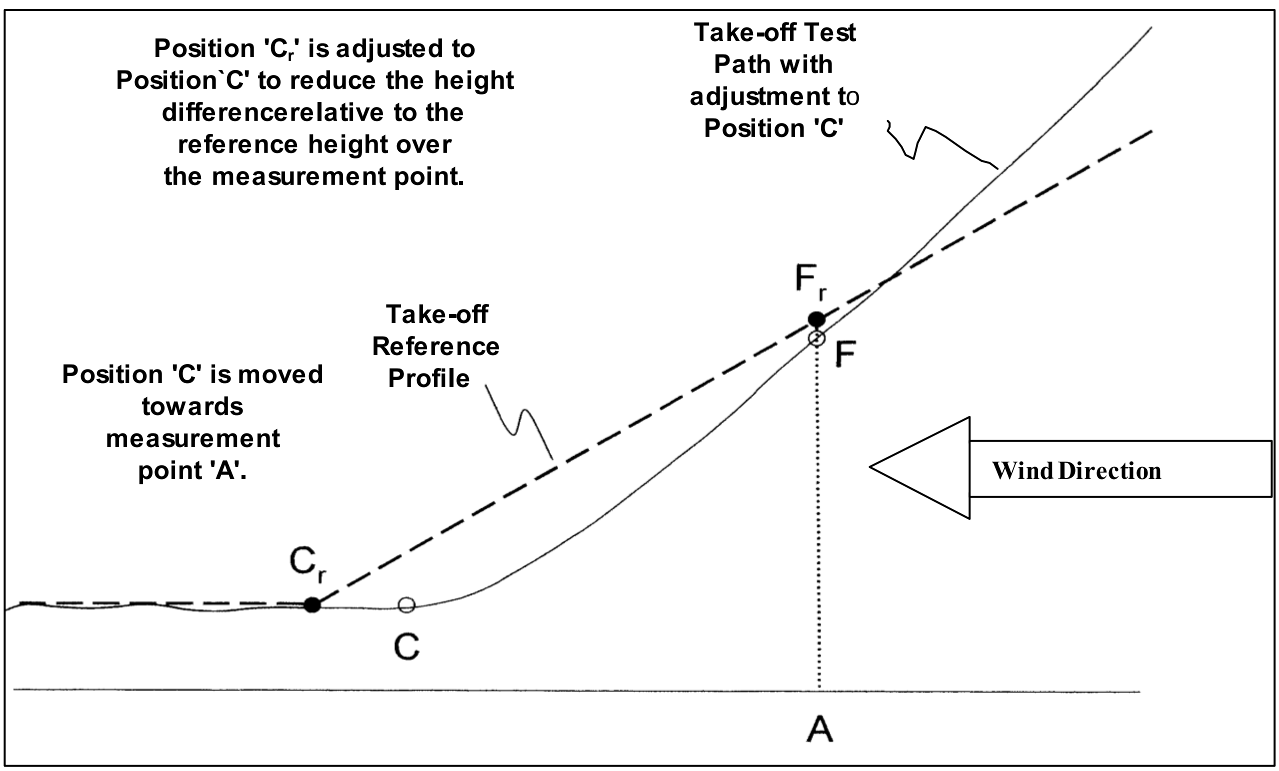


Figure 3-5 Adjustment of take-off profile position 'C' for headwind

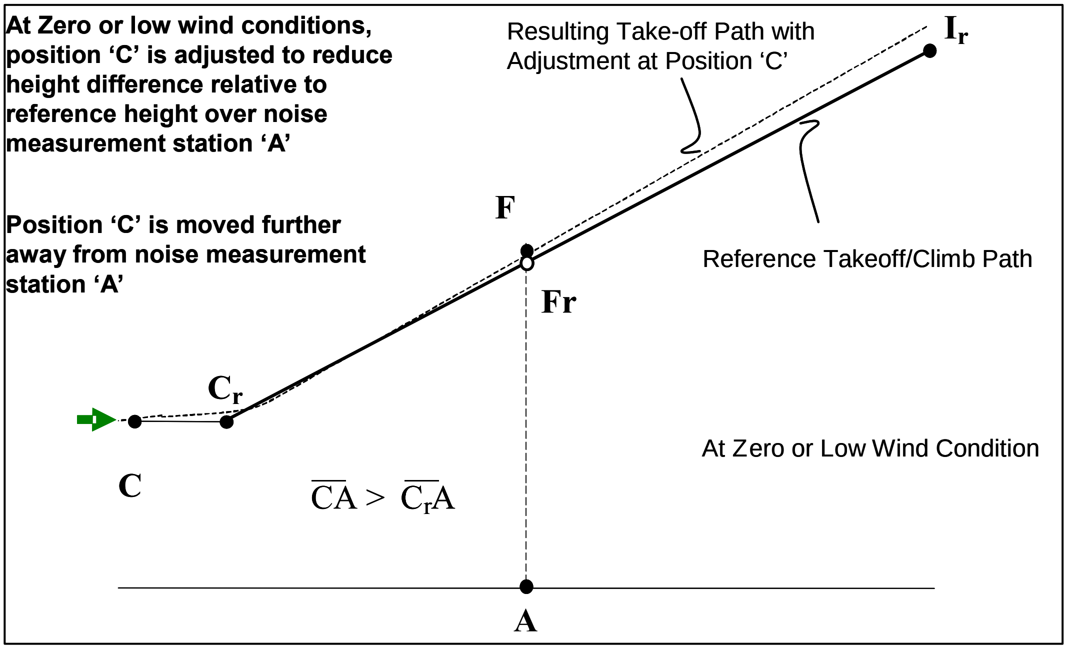


Figure 3-6 Adjustment of take-off profile position 'C' for zero or low wind

(5) Vertical Adjustment of Climb Initiation

Subject to approval by the certificating authority, the height of the initial level flight may also be varied in order that the height (distance) adjustment associated with the climb phase can be minimized. This is an equivalent procedure, which can be used in the place of adjusting the horizontal location of Position C from the flight track noise measuring point to achieve the same result.

The applicant should note that under many test conditions no such adjustments are required to comply with the data adjustment procedures defined in 8.3 of Appendix 2 of the Annex.

Note.- The above procedures for horizontal or vertical adjustment of climb initiation are based on consideration of the height above the flight track or centre noise measuring point, even though the adjustments to the noise measurements are applied for the PNLTM point. However, since the PNLTM point, which is normally within close proximity of the overhead point, cannot be determined until after the noise analysis is conducted, use of height over the noise measuring point to determine the location of Position C (or the initial horizontal height) is acceptable.

(6) Practice Flight

Irrespective of which method is used to control the height over the flight track noise measurement point, an applicant may find it helpful, if not essential, to conduct a number of practice or pre-noise certification test runs to adjust the height/location of Position C. With prior approval of the regulatory authority these practice runs can be excluded from the noise compliance evaluation. These runs should also be documented in the Noise Certification Report as practice flights.

(7) Power Setting

Take-off power at Sea Level and 25°C has to be applied at position C to initialize the climb. On many helicopters the airworthiness power limit will be set by the take-off gearbox torque limit. When this is not the case the take-off torque will be that torque determined during the airworthiness certification and will be based on the minimum specification engine(s) power.

In some cases the applicant may find that the take-off gearbox torque limit to which the helicopter is to be airworthiness certificated has not been approved and hence cannot be used during the noise certification test. When testing only at a lower torque is possible, the certificating authority may approve, as an equivalent procedure, the extrapolation of noise data from lower torque settings. Tests conducted at the maximum available and a minimum of two lower gearbox torque settings would be required for extrapolation, subject to certificating authority approval, to a higher torque value. Experience suggests that extrapolation of no more than 10 per cent is likely to be acceptable. The applicant will also need to document in detail the extrapolation procedure to be used.

(8) Rotor Speed

Rotor speed may be manually or automatically varied on some helicopters. On many designs variation in rotor speed can occur due to the limits of the engine/rotor governing system. In order that the noise levels are representative of normal take-off operation, the rotor speed is to be the maximum normal value associated with the reference take-off airspeed. Since on most helicopters small rotor speed changes occur during a stabilized flight, a ± 1 per cent rpm variation in the rotor speed is allowed.

Note.- Noise measurements should be made at the maximum rotor speed during normal operations. Testing at the maximum tolerance rpm is not required.

On some helicopter designs more than one rotor speed may be available (see 3.2.3.1.6). If multiple rotor speeds can be used for normal operations, then noise certification has to be conducted at the highest value allowed at the reference conditions. If the highest speed is limited to special operations or if the helicopter is configured such that the highest rotor speed cannot be used at the reference conditions or test height then, subject to certificating authority approval, testing at a lower rotor speed may be allowed.

On some helicopter designs, rotor speed may be automatically varied within the 10-dB down period. In such cases, a reference rotor rpm schedule as a function of position along the reference flight path should be defined and tests should be conducted so as to maintain the test rotor rpm within ±1% of the reference rpm schedule. If the variation in rotor speed results in changes to the best rate of climb, a non-linear reference flight profile should be defined and used in the calculation of reference distances for adjustments of the noise data to reference conditions.

For example, for a helicopter that automatically varies rotor speed (Nr) during Take-off, a reference rotor speed schedule may be defined as a function of height above ground level along the reference flight path during the 10 dB-down period as illustrated in Figure 3-7. In the typical case where the helicopter is main gearbox torque limited at the noise certification reference conditions, the rotor speed schedule may also result in a non-constant (curved) reference flight path segment during the Nr transition as illustrated in Figure 3-7. The ±1% test requirement for rotor speed would be applied to the reference rotor speed schedule as shown in Figure 3-7.

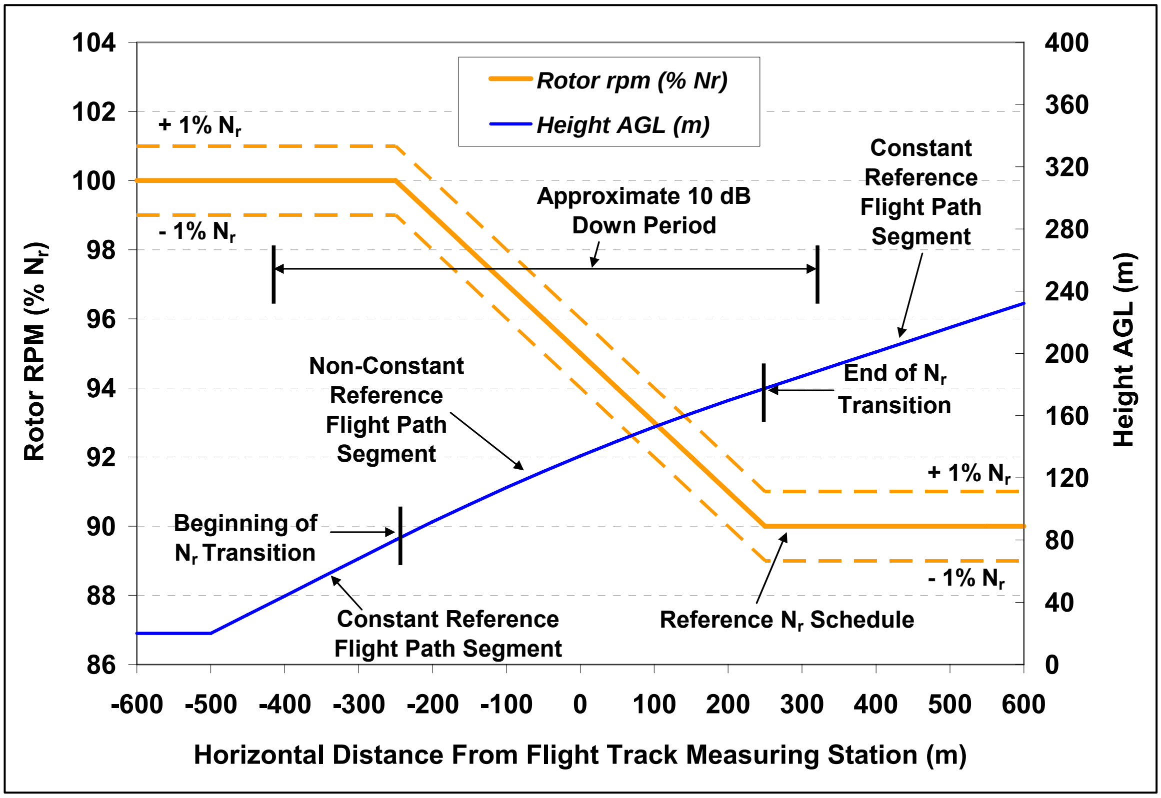


Figure 3-7 Example of a Reference Take-off Flight Path and Rotor Speed Schedule (with +/-1% N_r Limits) for a Variable Rotor Speed Helicopter

(9) Flight Path Guidance

To meet the requirement of being within ± 10° of the vertical, the applicant may need to use flight track markings which are clearly visible, and/or on-board flight track guidance instrumentation and a real time position measuring system or some other approved method of checking that this requirement is satisfied. Pilot visibility of the ground when climbing may be somewhat limited and thus markers well ahead of the noise measuring point may be required. Some of the flight path measurement systems outlined in 2.2 provide flight track data in real time, or in a short period after the test run. In this case the applicant will readily be able to determine if a test run is within the allowable deviation limits. If a simpler system is utilized, such as photographic scaling based on the use of still cameras, the applicant may find it useful, if not essential, to develop a method to enable timely confirmation that the test run is acceptable. The actual height and off-track deviations do not need to be established at the time of the test run. However the applicant needs to ensure that otherwise acceptable test runs are not rejected during analysis for failing to meet the ± 10° limit for lateral deviation.

GM No. 1 A2 8.2.2
[Overflight configuration]

(1) Reference Overflight Profile

Chapter 8 of the Annex specifies the reference procedure as a level overflight at 150 m (492 ft) above the ground at the flight track measurement point as illustrated in Figure 3-8, in which the reference flight profile is indicated as D_r to J_r and the test profile as D to J.

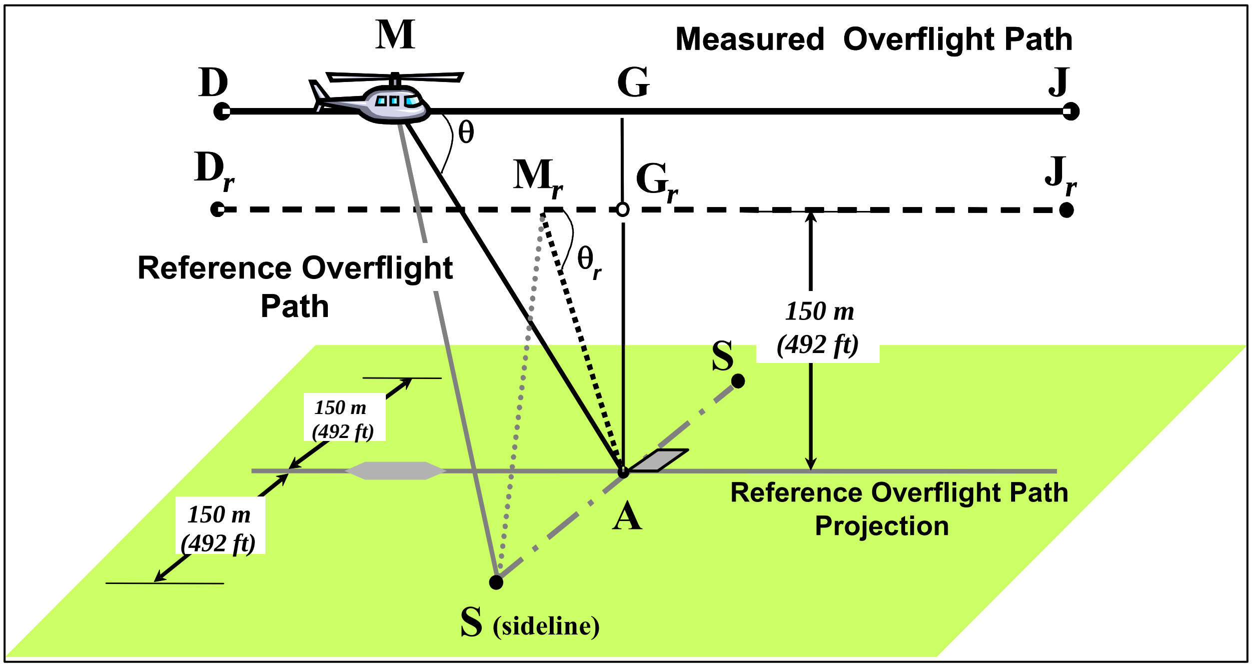


Figure 3-8 Comparison of measured and reference overflight profiles

The reference airspeed is $0.9V_H$, $0.9V_{NE}$, $0.45V_H$ + 120 km/h ($0.45V_H$ + 65 knots), or $0.45V_{NE}$ + 120 km/h ($0.45V_{NE}$ + 65 knots), whichever is less, throughout the 10 dB-down period. The rotor speed (rpm) is fixed at the maximum normal operating value. Note that if V_H is greater than V_{NE} then the reference airspeed will be related to V_{NE}.

Note.- For clarity the location of the test and reference PNLTM points, M and M_r, are illustrated at the same position in relation to both the centre line noise measurement point A and the lateral noise measurement point location S. Normally however M, and hence M_r, will be a different position on the test and reference flight path for each noise measurement point.

GM No. 2 A2 8.2.2
[Overflight test conditions]

(1) Flight Path Deviations

To enable the flyover noise characteristics to be obtained, the overflight test has to be a level flight at a fixed height above the flight track noise measurement point. The test runs also have to be within ± 10° or ± 20 m (± 65 ft), whichever is the greater, from the vertical throughout the 10 dB-down period. The ± 20 m (± 65 ft) is not relevant in the case of overflight since the off track deviation allowed, at the test height, is controlled by the ± 10° requirement.

(2) Test Airspeed Tolerance

The flight airspeed is defined in 8.6.3 of Chapter 8 of the Annex and a ± 9 km/h (± 5 kt) tolerance from the reference airspeed during each overflight is allowed within the 10 dB-down period. The power is to be stabilized and the mean value of the rotor speed during the 10 dB-down period is to be within ± 1 per cent of the normal operating rpm value for each overflight.

(3) Source Noise Adjustment Testing

The applicant should consider the requirement for source noise adjustments since it is unlikely that the tests can be conducted precisely at the reference temperature of 25°C (77°F), reference rotor speed and reference airspeed. This dictates that, if the test advancing blade tip Mach number is different from the reference Mach value, the development of a PNLTM versus advancing blade tip Mach number sensitivity curve is necessary. This requires testing at different flight speeds around the reference flight speed. The number of additional test runs will to some extent depend on the character of the variation of PNLTM with flight speed, but since this cannot be determined until after the analysis is complete, conservative estimates for the number of additional test runs and the actual airspeeds to be used need to be considered.

Note.- The Equivalent Mach Number Procedure, discussed in Paragraph 11 of AMC A2 8.2.2, is an acceptable method of compliance that eliminates the need for a source noise adjustment.

(4) Helicopter Test Mass

The mass of the helicopter during the noise certification demonstration (see 8.7.11 of Chapter 8 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the overflight demonstration. At least one overflight test must be completed at or above this maximum certificated mass. If the value of the maximum take-off mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the Rotorcraft Flight Manual.

AMC A2 8.2.2
[Overflight test procedures]

(1) V_H

V_H is defined as the airspeed in level flight at the reference conditions and maximum certificated take-off mass, and is obtained using the minimum specification engine(s) torque at maximum continuous power. V_H will need to be determined specifically for the noise certification overflight tests, since its determination is not required for the airworthiness certification. V_H, by itself, is never limited by airworthiness considerations. However the maximum continuous power on which it is based may be limited due to airworthiness issues and that, in effect, could limit the value of V_H.

(2) V_{NE}

V_{NE} is determined as a part of the airworthiness approval and will therefore be readily available.

(3) Reference Airspeed

On some helicopters V_H may be in excess of the level flight V_{NE} imposed and approved by the certification authority. The intent of noise certification is not to relate test airspeeds to reference airspeeds that may be beyond the airworthiness V_{NE} limit of the helicopter. Under 8.6.3 of Chapter 8 of the Annex, V_{NE} would therefore apply in place of V_H. Also on some helicopters with high airspeed capabilities, the typical cruise airspeed will be less than $0.9V_H$ (or $0.9V_{NE}$) and thus if $0.9V_H$ (or $0.9V_{NE}$) was used as the reference, it would no longer be representative of a cruise flight. In this case a lower airspeed of $0.45V_H$ + 120 km/h ($0.45V_H$ + 65 kt) or $0.45V_{NE}$ + 120 km/h ($0.45V_{NE}$ + 65 kt) is used. This applies when $0.9V_H$ (or $0.9V_{NE}$) is 240.8 km/h (130 kt) or higher (i.e. when V_H (or V_{NE}) is 267.6 km/h (144.4 kt) or higher). Thus the reference airspeed will be the least of the following four airspeeds:

a) $0.9V_H$;

b) $0.45V_H$ + 120 km/h ($0.45V_H$ + 65 kt);

c) $0.9V_{NE}$; or

d) $0.45V_{NE}$ + 120 km/h ($0.45V_{NE}$ + 65 kt).

(4) Flight Path/Height Determination

The flight path is required to be "straight and level". Since there is no requirement for the terrain over which the helicopter is flying to be perfectly level, the height of the helicopter above the ground may vary slightly over the distance corresponding to the 10 dB-down period. If a ground-based system such as a differential GPS base station or a 3 camera system is used, then the flight path/height determination will need to account for the actual ground elevations at which the system components are placed.

(5) Flight Track Deviations

The allowable off-track deviation from the vertical above the reference track is limited by ± 10° or ± 20 m (± 65 ft), whichever is the greater. The height above the flight track noise measurement point must be within ± 9 m (± 30 ft) of the reference height of 150 m (492 ft). The allowed off track deviation is ± 24.9 m (± 81.5 ft) at the lower height limit of 141 m (462 ft) and is ± 28 m (± 92 ft) at the higher height limit of 159 m (522 ft). Thus the helicopter must pass through a "test window" located above the reference flight track, as illustrated in Figure 3-9, throughout the 10 dB-down period.

(6) Number of Test Runs

At least six overflight test runs are required with equal numbers with headwind and tailwind. Since the data will be adjusted, there are no requirements for these to be flown in pairs immediately one after the other.. Conducting the test runs in pairs, however, would alleviate the need to take the wind direction into account.The applicant will therefore typically find it expedient to conduct tests in such a manner and include additional pairs of test runs in case any of the test runs are proved invalid on subsequent analysis. In addition to the simultaneous noise measurement at the three measurement points, the applicant should note that synchronized noise and flight path measurements are required throughout the 10 dB-down period. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process.

Note.- If the absolute wind speed component in the direction of flight, as measured at a height of 10 m (33 ft) above ground, is less than 9 km/h (5 kt), then the effect of wind direction can be considered to be negligible. In this case the measured overflight can be considered to be either a headwind or tailwind test run.

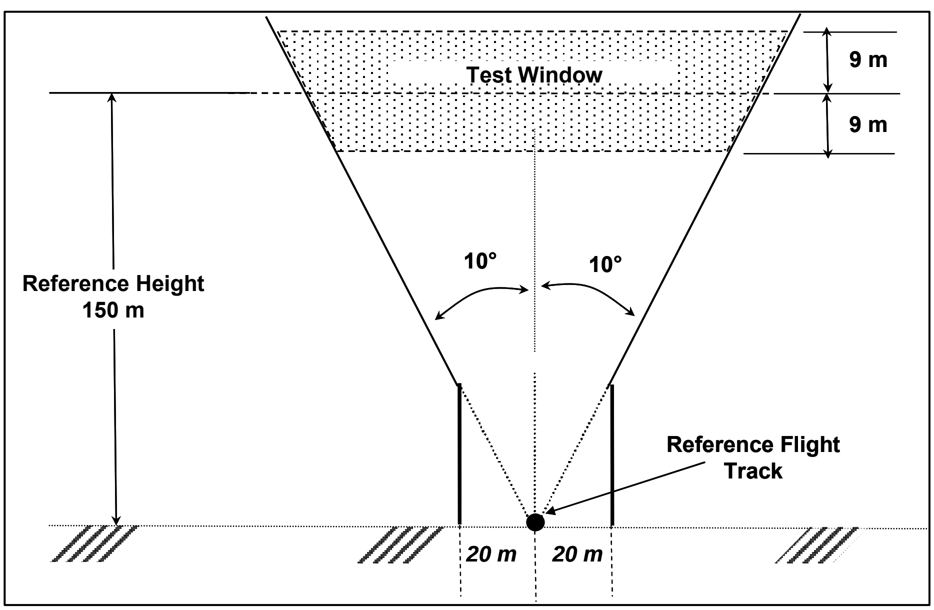


Figure 3-9 Flight boundaries for overflight test condition

(7) Test Height

Since most test sites will not be completely flat the height (distance) between the helicopter and ground track will vary during the overflight. The flight path and the relative position between the helicopter and the reference profile can be determined using a number of different systems (see 2.2).

(8) Test Airspeed

The overflight test airspeed will be either the reference airspeed if a source noise adjustment is applied, or the adjusted reference airspeed if the equivalent Mach number method is used. The applicant should also note that the airspeed defined in the Annex is the true airspeed (TAS). Since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and test-day meteorological conditions should be used to determine the indicated airspeed (IAS) for use by the pilot.

(9) Source Noise Adjustment

Source noise adjustments have to be developed for noise data measured at the centre, left sideline and right sideline microphones. Test runs are conducted in two directions. "Left sideline" and "right sideline" are defined relative to the direction of flight for each test run. It follows that if a microphone is "left sideline" for a test run in one direction then it is "right sideline" for a test run in the other direction. The applicant should take care to ensure the measured noise is correctly designated.

Two methods have been adopted by various applicants to establish the source noise adjustment. The first involves testing, relative to the reference flight speed, at a number of fixed airspeeds such as V_r -18.5 km/h (10 kt), V_r - 37 km/h (20 kt) and V_r +18.5 km/h (10 kt). To retain the same accuracy as associated with the reference condition, six test runs (three in each direction) at each of the additional flight airspeeds are typically needed. A sensitivity curve is then developed from this data as indicated in Figure 3-10. Other applicants have tested over a range of airspeeds from, for example, V_r - 37 km/h (20 kt) to V_r + 18.5 km/h (10 kt) and developed a sensitivity curve in this manner. In this case at least six valid test runs are, of course, still required at the reference airspeed. A statistically acceptable curve using this method is illustrated in Figure 3-11. The number of test runs required for either method for developing source noise sensitivity curves is subject to approval by the certificating authority.

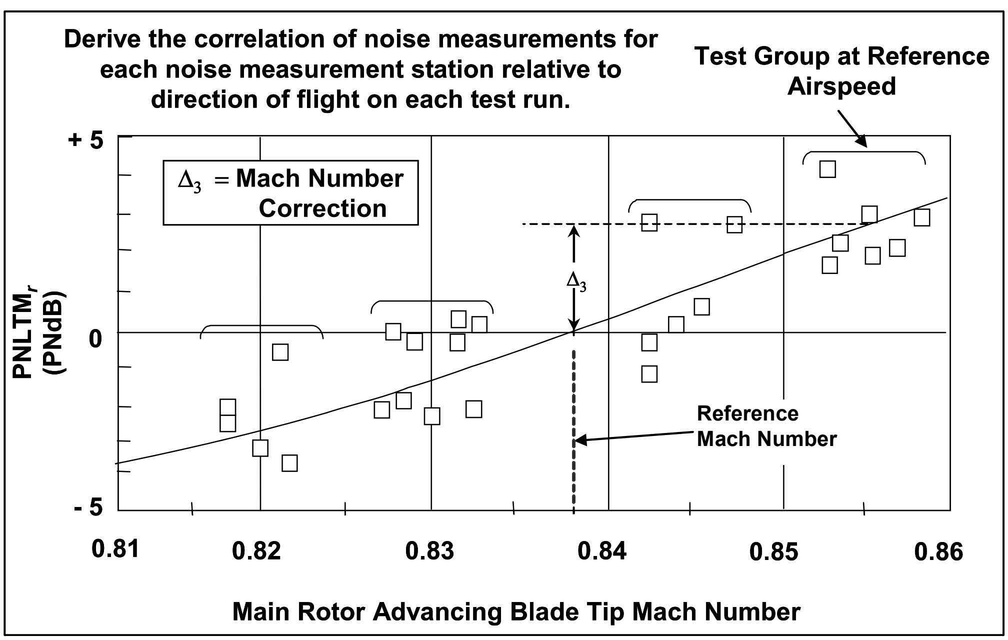


Figure 3-10 Example of source noise correlation using pooled (clustered) test data

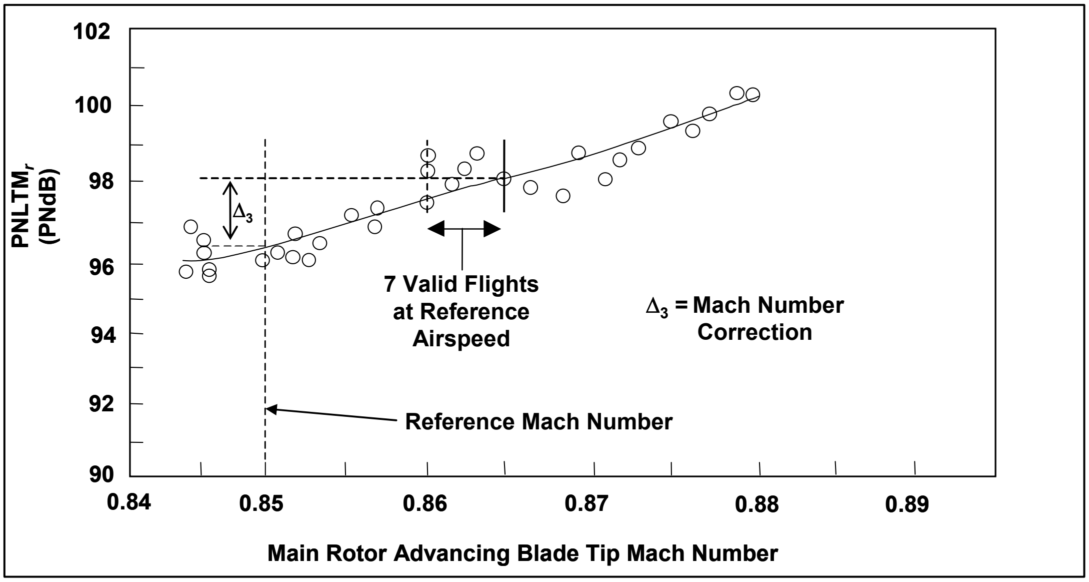


Figure 3-11 Example of source noise correlation using distributed test data

(10) Equivalent Mach Number Test Procedure

To avoid testing at a large number of airspeeds over a wide airspeed range to develop a PNLTM versus Mach number sensitivity curve, the applicant may, subject to approval by the certificating authority, use the equivalent procedure presented in 3.2.3.2.2. With this procedure a single series of test runs is conducted at an adjusted reference airspeed. The minimum number of acceptable test runs is six (three in each direction) and the previous comments on the need for the applicant to consider making additional test runs to cover the case where some test runs may subsequently be found to be invalid is equally applicable. When this procedure is used the airspeed tolerance is reduced from ± 9 km/h (± 5 kt) to ± 5 km/h (± 3 kt). In addition all the other limits applicable to testing at the reference airspeed also apply.

This equivalent procedure requires measurement of the on-board outside air temperature just prior to each test run. Under stable ambient temperature conditions this is relatively straightforward and calculations can be made on the ground prior to each test run. When changes in temperature are occurring during the test period it may be necessary to take the on-board temperature in flight just prior to reaching the initial 10 dB-down point. These can be used to make the necessary calculations to adjust the flight airspeed appropriately and ensure that the applicable adjusted airspeed and reference advancing blade tip Mach number are used for the test run.

When this equivalent procedure is used the test runs are conducted at the reference blade tip Mach number and hence no additional source noise adjustments are required. The applicant should also note the airspeed defined in the Annex is the true airspeed (TAS) and since most airspeed instruments do not indicate the TAS value, airspeed calibration curves and test-day meteorological conditions should be used to determine the indicated airspeed (IAS) for use by the pilot.

(11) Equivalent Mach Number Test Speed

Each overflight noise test must be conducted such that the adjusted reference true airspeed (V_{ar}) is the reference airspeed (V_r specified in 8.6.3 of Chapter 8 of the Annex), adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions.

Note.- The reference advancing blade tip Mach number (M_r) is defined as the ratio of the arithmetic sum of the main rotor blade tip rotational speed (V_T) and the helicopter reference speed (V_r) divided by the speed of sound (c_r) at 25°C (346.1 m/s) such that:

$$M_r = \frac{V_T + V_r}{c_r}$$

and the adjusted reference airspeed (V_{ar}) is calculated from:

$$V_{ar} = c\left(\frac{V_T + V_r}{c_r}\right) - V_T$$

where c is the speed of sound calculated from the onboard measurement of outside air temperature.

(12) Rotor Speed / Flight Path Guidance

The comments on rotor speed and flight path guidance discussed in AMC No. 2 A2 8.2.1 are equally applicable for overflight noise testing.

GM No. 1 A2 8.2.3
[Approach configuration]

(1) Reference Approach Profile

The reference approach profile is illustrated in Figure 3-12 together with an idealized measured test profile. The Annex requires flight tests to be conducted under stable flight conditions within a 6° ± 0.5° approach angle with the noise data adjusted to a 6° reference profile. The reference airspeed is V_y, as used for the take-off test, or the lowest airworthiness-approved speed for approach, whichever is the greater.

Note.- For clarity the location of the test and reference PNLTM points, N and N_r, are illustrated at the same position for both the centre line noise measurement point A and the starboard lateral noise measurement point S. Normally however N, and hence N_r, will be a different position on the test and reference flight paths for each noise measurement point.

(2) Reference Approach Path

The touchdown position is located 1140 m (3740 ft) from the intersection of the 6º reference approach path with the ground plane through position A. The flight path reference point H_r is located 120 m (394 ft) above position A on the ground.

(3) Helicopter Test Mass

The mass of the helicopter during the noise certification demonstration (see 8.7.11 of Chapter 8 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum landing mass for the approach demonstration. At least one approach test must be completed at or above this maximum certificated mass. For most helicopters the maximum landing mass will be the same as the maximum take-off mass and as a result the same maximum mass will apply to all three test conditions. If the value of the maximum landing mass selected for noise certification is less than that used for airworthiness certification, then the lower mass may become the operating limitation defined in the appropriate section of the Rotorcraft Flight Manual.

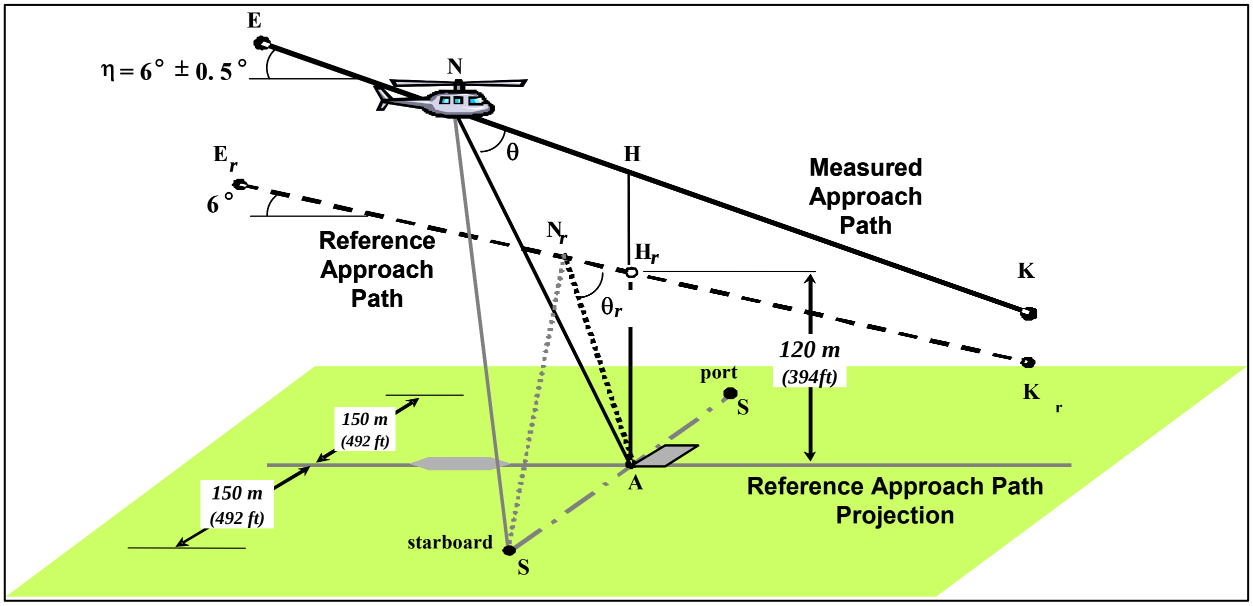


Figure 3-12 Comparison of measured and reference approach profiles

GM No. 2 A2 8.2.3
[Approach test conditions]

(1) Test Airspeed

Since there is no single common or well defined approach airspeed applicable to helicopters, the tests are conducted at the certificated best rate of climb airspeed V_y,which approximates to a typical approach speed, or the lowest airworthiness approved speed for approach, whichever is the greater.

(2) Flight Path Deviations

Test runs are to be conducted with a 6° ± 0.5° approach angle using stabilized flight airspeed within ± 9 km/h (± 5 kt) of the reference V_y airspeed, rotor speed within ± 1 per cent of the normal maximum operating rotor speed, and power. To limit the magnitude of the off-track distance, the flight path is to be maintained to within ± 10° or ± 20 m (± 65 ft) of the vertical, whichever is the greater throughout the 10 dB-down period (see Figure 3-13).

(3) Maximum Noise Level Measurement

The intent of the Standard is to obtain noise measurements of the maximum noise levels which are likely to occur in practice during an approach flight condition. Since it is known that the maximum main rotor noise, known as Blade Vortex Interaction (BVI) or blade slap, occurs at around 6º descent angle at a constant speed of V_y this has been chosen as the reference condition. Only in the case where the lowest airworthiness approved speed for approaches is greater than V_y can any approach angle exception be allowed. This would require approval by the certificating authority and, irrespective of approved angle, the height above the ground at the flight-track measurement point would have to be 120 ± 10 m (394 ± 33 ft).

Experience suggests however that normally there is little difficulty in conducting the approach test with a descent angle of 6° at an airspeed of V_y within the allowable limits of ± 0.5° and ± 9 km/h (± 5 kt) respectively.

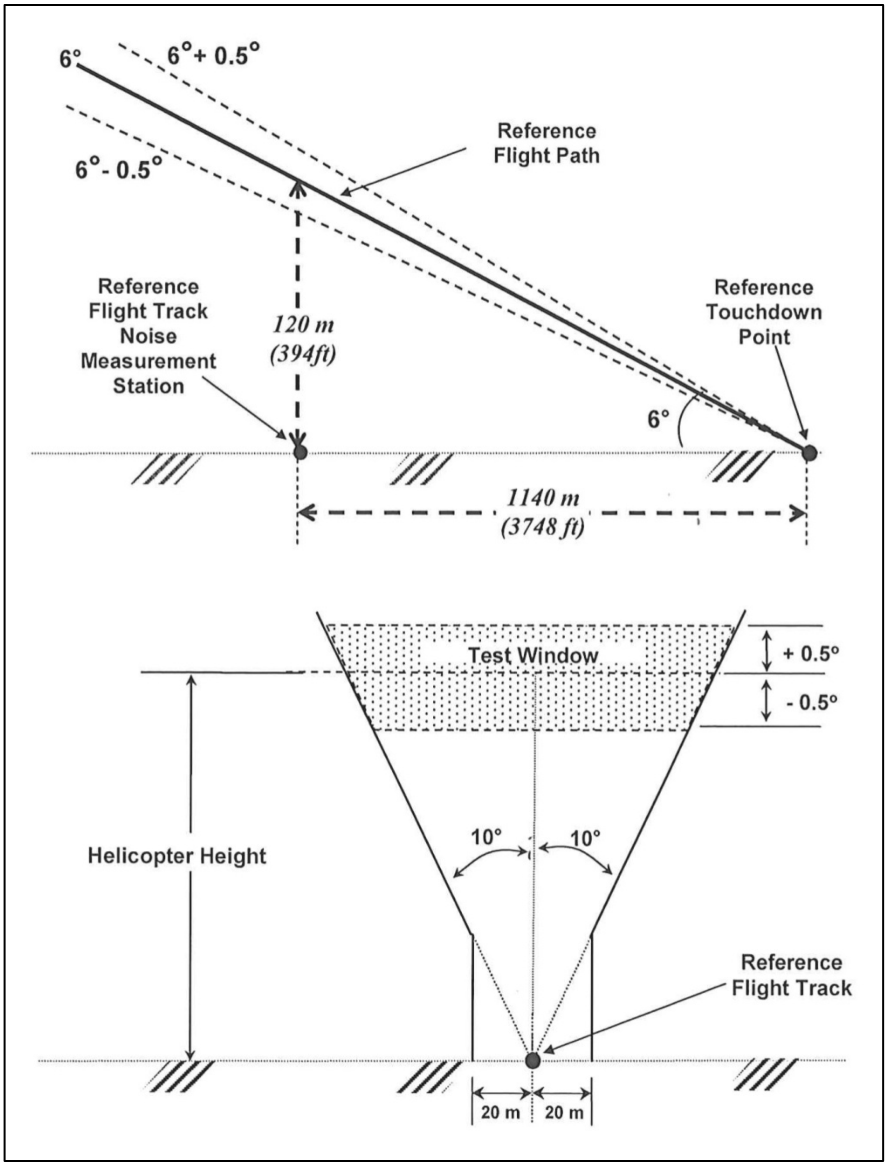


Figure 3-13 Flight boundaries for approach test condition

(4) Blade Vortex Interaction

Since a 6° descent angle at a speed of V_y is the approach condition likely to give the highest level of main rotor blade vortex interaction (BVI), the applicant should note that although on some helicopters this will result in a steady noise signature, on other helicopters the BVI noise character can vary even under nominally steady flight conditions. This may be subjectively noticeable but is not a technical problem since the average of six test runs will normally give results well within the maximum acceptable 90 per cent confidence interval of ± 1.5 EPNdB

(5) Practice Flights

Flying a constant 6º approach angle at a constant airspeed may be a somewhat demanding requirement for some helicopters, particularly since, in practice, a decelerating approach at a varying descent angle is the common method utilized in helicopter operations. The applicant/pilot may find merit, therefore, in the test procedure being practiced prior to any noise certification testing.

AMC A2 8.2.3
[Approach test procedures]

(1) Reference Approach Procedure

The 6° reference procedure is defined as being under stable flight condition in terms of torque, rotor speed, airspeed, and rate of descent throughout the 10 dB-down period. The reference airspeed is the best rate-of-climb true airspeed (TAS) V_y approved by the certificating authority

(2) Number of Test Runs

At least six test runs are required with simultaneous noise measurements at each of the noise measurement points. The applicant should, as in the case of take-off and overflight, consider additional test runs to ensure that a sufficient number of valid data points are available. Synchronized noise and flight path measurements are required throughout the 10 dB-down period. If additional test runs are conducted and more than six valid noise measurements are simultaneously obtained at all three measurement points, then the results of such test runs are also required to be included in the averaging process for calculating EPNL. The results of test runs without simultaneous noise measurements at all three measurement points are not included in the calculation process

(3) Flight Path Guidance

The helicopter has to fly within the 6° ± 0.5° approach angle range and within ± 10° or ± 20 m (± 65 ft), whichever is greater, of the vertical above the reference flight track throughout the 10 dB-down period. Thus the helicopter has to fly within a 'rectangular funnel' as illustrated in Figure 3-13. To ensure flight within these limits positive guidance to the pilot will most likely be required. This guidance can take many different forms, varying from on-board instrumentation providing, for example, a box in which the pilot flies the aircraft, cross hairs where the pilot flies the helicopters at the center, or an external light guidance system such as a VASI or PLASI located at or near the imaginary touchdown point where the 6° angle reaches the ground. The system chosen by the applicant should be approved by the certificating authority prior to testing.

(4) Flight Path Intercept

Section 8.2.3 of Appendix 2 of the Annex specifies that each approach test run be continued to a normal touchdown. The noise data is taken during stabilized flight condition within the 10 dB-down period and thus may not be impacted by the flare or the final touchdown. Also for flight safety reasons it may not be desirable to continue the test run on a 6° profile to the ground. As a result an equivalent procedure may be used, subject to approval by the certificating authority, where the helicopter can break-off from the descent after the second 10 dB-down point is reached. This can be completed without the need to actually land the helicopter, offering considerable savings in flight time providing the other requirements are met.

(5) Wind Direction

Although the Annex does not specifically require that the test runs be conducted into the wind, this is advisable since it will provide a safer and more stable flight environment.

(6) Rotor Speed Guidance

The comments on rotor speed guidance discussed in AMC No.2 A2 8.2.1 are equally applicable for approach noise testing.

(7) Other Test Requirements

The comments on the measurements of height, flight airspeed variation, and rotor speed discussed in AMC A2 8.2.2 are equally applicable for approach.

GM A2 8.3
[Adjustments of PNL and PNLT]

(1) Units

For calculations in SI units the distances are measured in metres and $\alpha(i)$ and $\alpha(i)_0$, used in determining Δ_1, are expressed in dB/100 m. In this case a constant factor of 0.01 is used for the first and second terms of the Δ_1 adjustment. If the English system of units is used the distances are measured in feet and $\alpha(i)$ and $\alpha(i)_0$ are expressed in dB/1000 ft. In this case a constant factor of 0.001 is used for the first and second adjustment terms.

(2) Zero Adjustment Test Window

If the test conditions fall within the "zero attenuation adjustment window" shown in Figure 3-29 of 3.2.3.2.1, the sound attenuation adjustment for the effects of atmospheric absorption of the test data may be taken as zero subject to prior approval by the certificating authority (see 3.2.3.2.1 for details).

AMC A2 8.4
[Duration Adjustment to EPNL]

(1) Adjustment for Flight Path

The distances associated with the PNLTM position used to calculate the adjustments under 8.3 of Appendix 2 of the Annex are used in the calculation of the first term of the Δ_2 duration adjustment to EPNL.

Note.- If the test conditions fall within the window shown in Figure 3-29 of 3.2.3.2.1, the ratios of the reference and test slant distances for the propagation path adjustments in the first term of the adjustments to the duration correction may be replaced by the ratios of the reference and test distances to the helicopter when it is overhead the flight track noise measurement point (see 3.2.3.2.1 for details).

(2) Adjustment for Ground Speed Differences

The ground speed must not be confused with the actual airspeed used during the tests, and will be a function of both the flight test airspeed and wind speed. The reference ground speed V_{Gr} (based on the assumption of a zero wind condition) is, for take-off and approach, the horizontal component of the reference airspeed V_y (in true airspeed) defined in 8.6.2 and 8.6.4 of Chapter 8 of the Annex and, for overflight, the reference airspeed defined in 8.6.3 of Chapter 8 of the Annex. For take-off the reference ground speed is the horizontal component of the best rate of climb airspeed V_y (in true airspeed), i.e. $V_{Gr} = V_y \cos\beta$.

(3) Microphone Height

To make the necessary adjustments, the microphone height above the ground, 1.2 m (4 ft), is to be taken into account when calculating the sound propagation path from the position at which the PNLTM occurs to the microphone.

Note.- For each noise measurement point during each test run, the PNLTM will normally occur at a different position on both the test and reference flight paths.

3.1.8 <u>Adjustment of aeroplane flight test results</u>

GM A2 9.1
[Adjustments to reference conditions]

(1) <u>Adjustments to Reference Conditions</u>

Most noise certification tests are conducted during conditions other than the reference conditions. During these tests the aeroplane may be at a different height over the microphone or deviate laterally from the intended flight path. The engine thrust (power), atmospheric conditions, aeroplane height and/or gross weight might also differ from reference conditions. Therefore, measured noise data should be adjusted to reference conditions to determine whether compliance with the certification noise limits of Chapters 3 or 4 of the Annex may be achieved. Adjustment procedures and analysis methods should be reviewed and approved by the certificating authority. The certificating authority should ensure that data adjustment and analysis methods that are proposed by applicants satisfy the requirements of the Annex and approved procedures. Any changes, including software revisions, firmware upgrades, or instrumentation changes are subject to certificating authority review before they can be used for noise certification evaluations. Program validation should be planned and the required information submitted to the certificating authority early in the certification cycle, since the time required for evaluation and approval may vary dependent upon the issues encountered.

(2) <u>Non-Positive SPLs</u>

Whenever non-positive one-third octave band aircraft noise levels are obtained, whether as part of the original one-third octave band analysis, or as a result of adjustments for background noise or other approved procedures, their values should be included in all relevant calculations. The practice of "Band-Dropping", where masked levels are methodically set equal to zero, is not considered to be an acceptable substitute for reconstruction of masked levels per the background noise adjustment guidance provided in 2.6.3. For any aircraft noise spectrum subject to adjustment to reference conditions, all one-third octave bands, including those containing masked levels or reconstructed levels, including values less than or equal to zero dB, should be adjusted for differences between test and reference conditions.

(3) <u>High Altitude Test Sites</u>

For test sites at or above 366 m (1200 ft), data shall be adjusted to account for jet noise suppression due to the difference in the engine jet velocity and jet velocity shear effects resulting from the change in air density. This adjustment is described in 3.3.2.3.

GM A2 9.1.1
[Origin of reference data]

(1) <u>Manufacturer's Data</u>

Adjustment of noise values from test to reference conditions should be based on approved manufacturer's data. Manufacturer's data should include:

a) Reference flight profiles during take-off with maximum gross weight;

b) Flyover, lateral, and approach engine thrust (power) or thrust settings at reference conditions;

c) Engine cutback thrust (power) reduction requirements at reference flyover conditions;

d) Data defining negative runway gradients (not applicable when an applicant uses flight path intercept techniques); and

e) Reference airspeeds during flyover, lateral, and approach tests at maximum gross weights.

GM A2 9.2.1
[Take-off configurations]

(1) Take-off Tests

The reference take-off configuration selected by the applicant should be within the approved airworthiness certification envelope. Special flight crew procedures or aircraft operating procedures are not permitted.

(2) Take-offs with Thrust (Power) Reduction

Figures 3-14 and 3-15 illustrate an example of the effect of thrust (power) reduction on the PNLT time history and the associated flight path. After thrust (power) reduction a slight decrease in the climb gradient may occur due to the thrust (power) lapse that results from increased height during the 10 dB-down period.

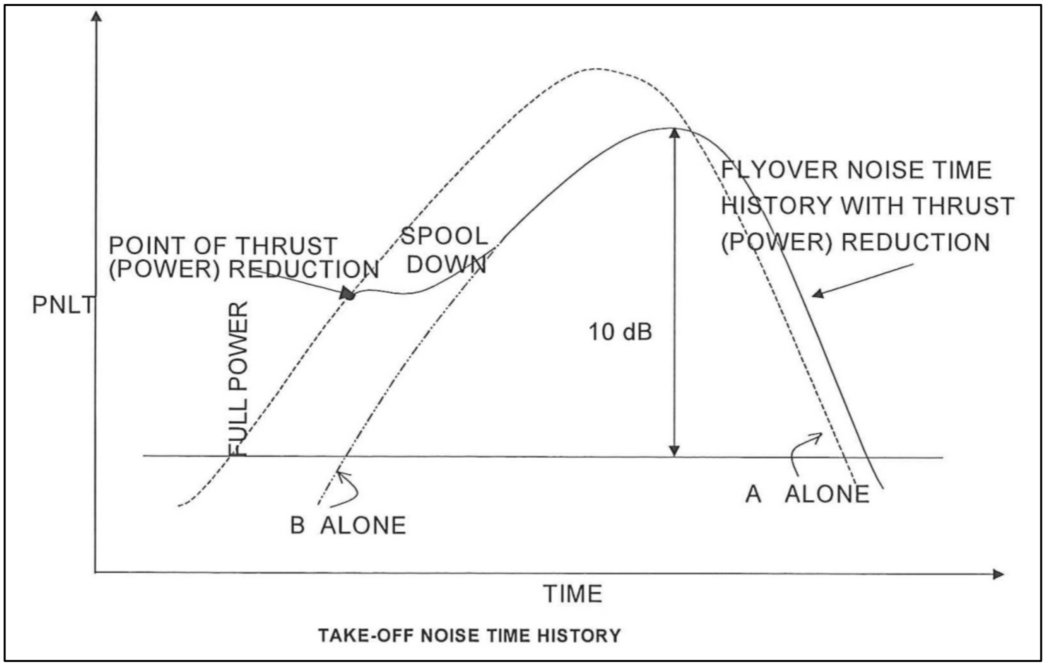


Figure 3-14 Take-off noise time history

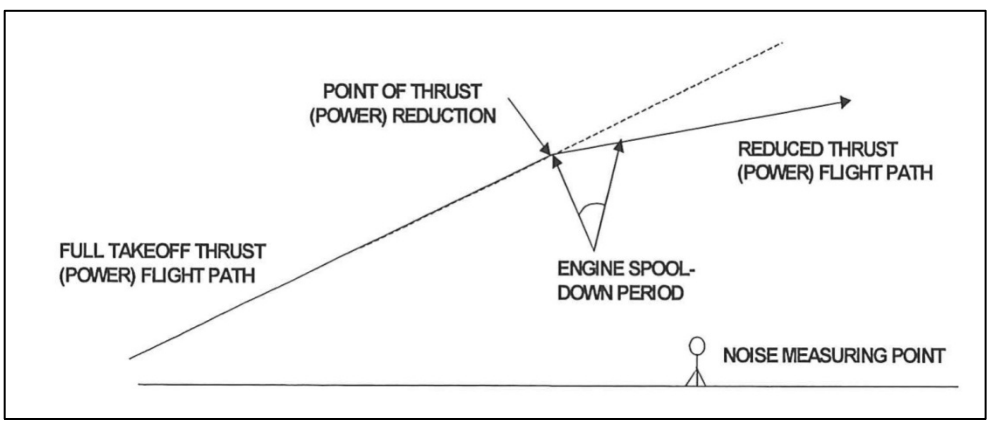


Figure 3-15 Take-off flight path over flyover measuring point with thrust (power) reduction

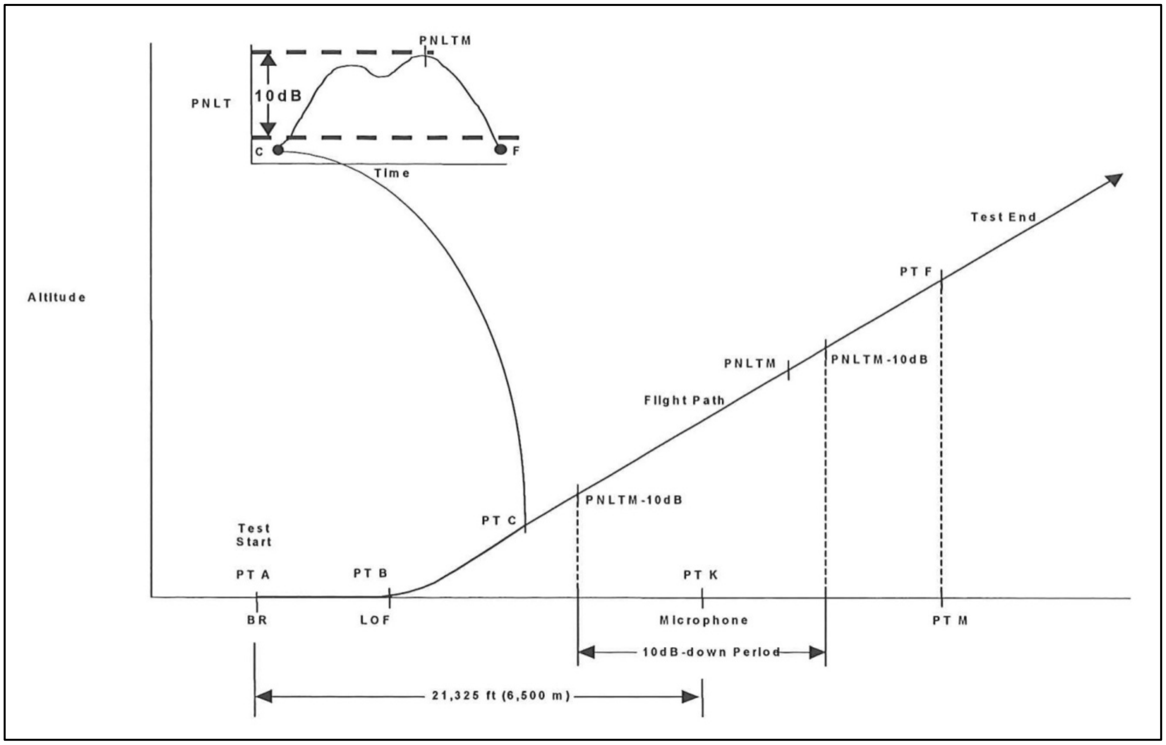


Figure 3- 16 Normal full thrust (power) take-off

(3) Full Thrust (Power) Take-offs

Full thrust (power) take-offs are also permitted as the reference flyover noise certification procedure and are a requirement for the lateral noise certification procedure. Maximum approved take-off thrust (power) is to be used from the start-of-roll (see Point A in Figure 3-16). Lift-off from the runway is at Point B, after which the landing gear is retracted, and flap positions adjusted. At Point C, the stabilized climb angle and airspeed are achieved while maintaining full take-off thrust (power). The aeroplane continues to climb until sufficiently past (Point F) to ensure that the 10 dB-down time noise value is measured at point K. Between Points C and F, the thrust (power), flight path and aircraft configurations are to be kept constant.

(4) Flight Path

Figure 3-17 illustrates the envelope for flight path tolerance within which the flight crew should fly between Points C and F. Certificating authorities have permitted a ± 20 per cent tolerance in overhead test height and a ± 10° lateral tolerance relative to the extended runway centre line. These tolerances permit the applicant to conduct testing during most wind conditions with minimal risk of re-testing being required due to off-target flight paths. In conjunction with the climb gradient and approach angle, these flight path deviation limitations define the take-off "flight path" through which the aircraft is to fly during and throughout the noise measurements (i.e. throughout the 10 dB-down period).

During flyover and lateral noise measurements, the extended centre line is not visible and it may be more difficult to conduct flight within the approved flight path, especially during conditions with anomalous winds aloft. Several methods have been devised to assist, and provide direction to the flight crew in order to stay within the required flight path envelope. Indicators located in the aeroplane cockpit can provide flight path direction and indicate deviations from the extended runway centre line. Transmissions from the aeroplane position-indicating system (e.g. microwave position system, precision DMU, or DGPS) can also provide useful inputs.

AMC A2 9.2.1
[Take-off test procedures]

(1) Target Test Conditions

Target test conditions are established for each noise measurement. These target conditions specify the flight procedure, aerodynamic configuration to be selected, aeroplane mass, engine thrust (power), airspeed, and, at the closest point of approach to the noise measurement point, aeroplane height. Regarding choice of target airspeeds and variation in test masses, the possible combinations of these test elements may affect the aeroplane angle-of-attack or aeroplane height, and therefore possibly the aeroplane noise generation or propagation geometry (see 3.2.1.1.2.1 for guidance on the choice of target airspeeds and variation in test masses).

(2) Flight Test Procedures

Before the start of noise testing the certificating authority should approve flight path tolerances (see GM A2 9.2.1). Except when take-offs with thrust (power) reduction are being demonstrated the engine thrust (power), aeroplane flight path and aerodynamic configuration should be kept constant between Points C and F (see Figure 3-17) during each approved certification flight test.

(3) Invalid Test Data

Noise measurements obtained when the aeroplane flies outside the approved flight path envelope between Points C and F (see Figure 3-17) during a noise certification test are considered invalid, and the noise measurement is to be repeated.

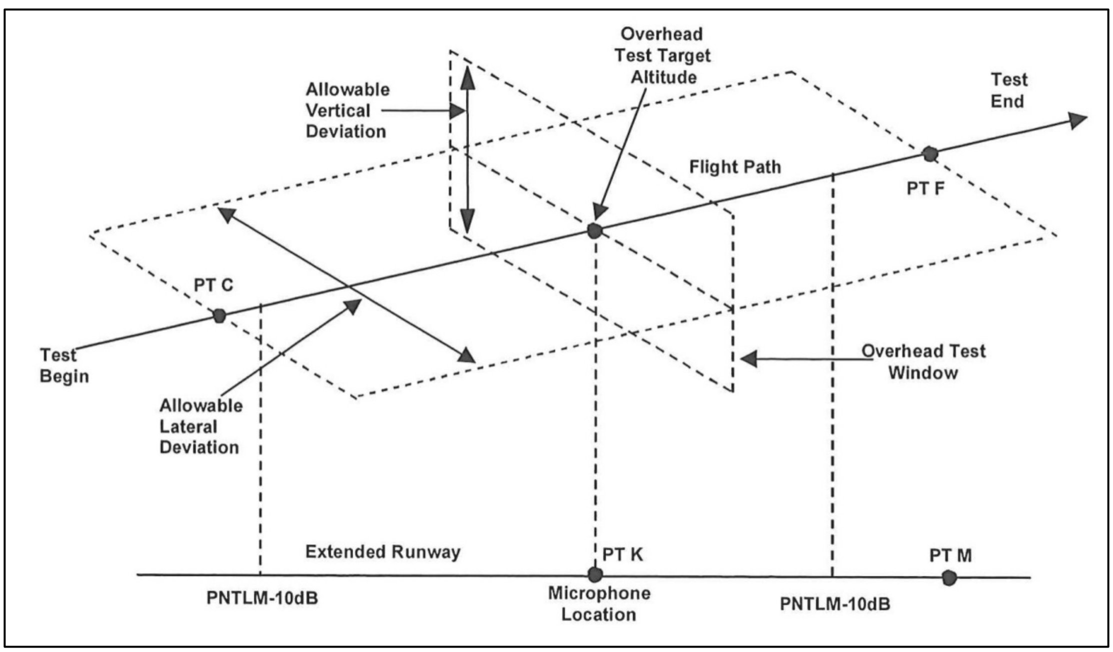


Figure 3-17 Take-off flight path tolerances

GM A2 9.2.2
[Approach test configuration]

(1) Approach Tests

Figure 3-18 depicts the reference approach flight test configuration for noise certification testing of aeroplanes. The approach angle (steady glide angle) for this condition is 3° ± 0.5°, and the target aeroplane height vertically above the noise measurement point is 120 m (394 ft). Maximum PNLT may occur before or after the approach noise measurement point.

(2) Flight Path Deviations

Approved height and centerline deviations along the extended runway approach flight path (see Figure 3-19) define an approved flight path envelope within which the flight crew should fly between Points G and I. In cases where the flight crew has a clear view of the airport runway during the approach, it is common for the crew to consistently fly within the approved flight path envelope. Therefore, the approved centre line and height deviations for approach conditions may be smaller than during take-off conditions.

AMC A2 9.2.2
[Approach test procedures]

(1) Target Test Conditions

Target test conditions should be established for each noise measurement. These specify the selected aerodynamic configuration, system operation, aeroplane mass, flight procedure such as complete landings or flight path intercepts, height, thrust (power), and airspeed during each noise measurement. The applicant is required to select the approved airworthiness configuration for the approach noise certification that produces the highest noise level (i.e. the most critical from the standpoint of noise). The airspeed requirement for subsonic jet aeroplanes is V_{REF} +19 km/h (V_{REF} + 10 kt). This airspeed is kept constant, within ±3.0 per cent, throughout the 10 dB-down period (i.e. between Points G and I in Figure 3-19). The aeroplane configuration (e.g. flap setting, A/C, and/or APU system operation) is to remain constant during the noise measurement period. Airspeed variations are measured in terms of the indicated airspeed (IAS) as determined by the pilot's airspeed indicator.

(2) Engine Idle Trim

For engines where the idle trim may affect the inter-compressor bleed valve schedule during the approach condition, the engine in-flight idle trim should be adjusted to the highest engine speed setting permitted by the engine manufacturer and consistent with airworthiness requirements. The engine may also provide ground idle trim adjustment, but the trim that needs adjustment is that which is operable during flight. In-flight idle trim may be adjusted to improve engine acceleration characteristics to satisfy airworthiness compliance. The higher idle trim will cause the highest engine speed and hence idle thrust (power) which results in a greater aeroplane angle of attack, and will result in the loudest approach noise required for certification. The applicant is to make those adjustments necessary to satisfy the airworthiness regulations. This idle trim adjustment may affect the performance or evaluation of approach Noise-Power-Distance (NPD) testing.

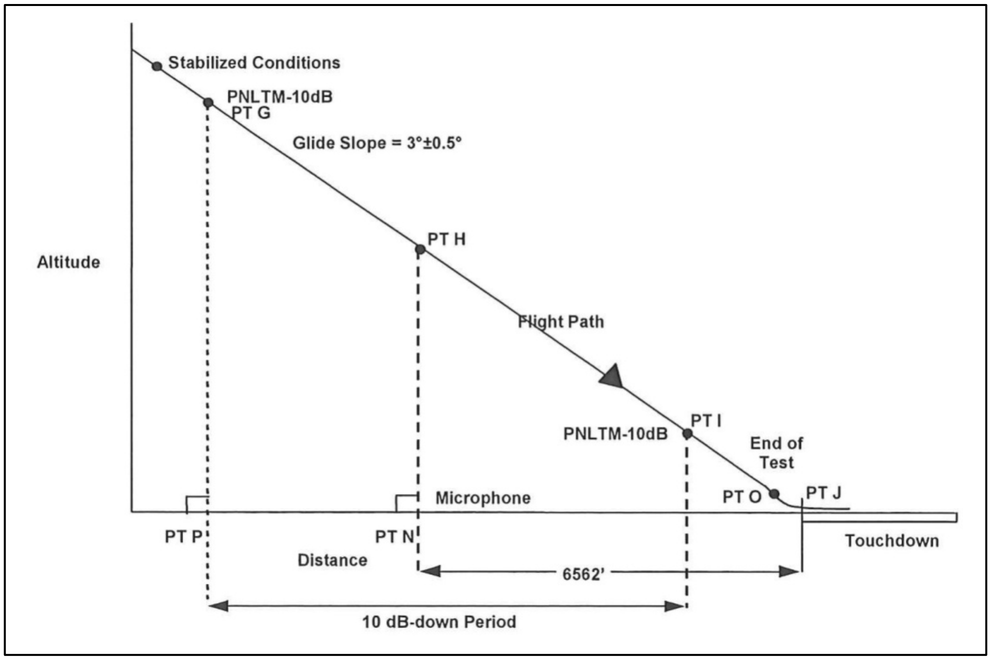


Figure 3-18 Approach with full landing

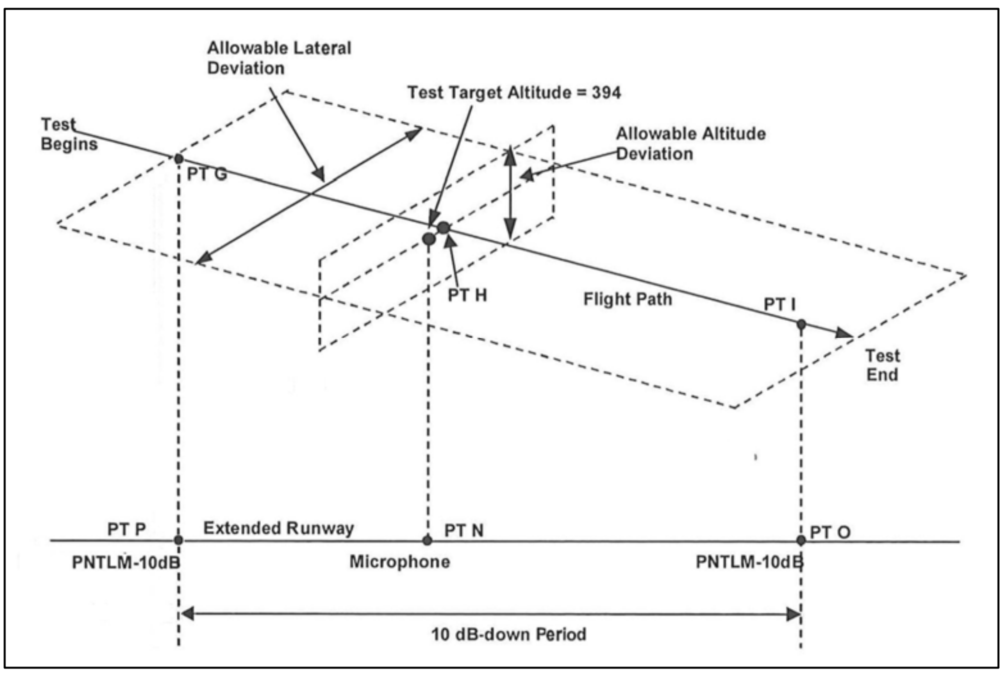


Figure 3-19 Approach flight path tolerances

(3) Internal Compressor Bleed Adjustment

The internal compressor bleed operation, sometimes referred to as the surge bleed valve (SBV) operation, should be adjusted within the engine manufacturer's specification to represent reference conditions as closely as possible. Most turbojet engines are equipped with internal compressor bleed systems. The internal compressor bleed operates to reduce the possibility of internal engine surges during rapid throttle movements. Some jet engines have overboard bleed systems that generate high noise levels. These systems normally operate above in-flight idle and do not present a problem unless the applicant chooses to prepare an NPD database and the thrust (power) settings higher than in-flight idle may be affected by the internal compressor bleed operation. The applicant is responsible for substantiating that either the internal compressor bleed operation does not affect the reference EPNL values during noise certification reference conditions, or the data contains the effects of the internal compressor bleed operation.

(4) Invalid Test Data

Noise measurements obtained when the aircraft flies outside the approved flight path envelope between Points G and I are invalid, and the noise measurement shall be repeated.

GM A2 9.3.5
[Lateral noise measurements]

(1) Measured Lateral Noise Levels

Measured lateral noise levels may not be the same at symmetrical noise measurement points even when the data are adjusted for aeroplane position for flight directly over the extended runway centre line. This non-symmetrical nature of measured sideline noise is primarily attributable to the direction of engine or propeller rotation. Because of inlet shielding, jet powered aeroplanes may exhibit 1-2 dB differences in lateral noise levels. Turbo-propeller powered aeroplanes can exhibit differences in lateral noise levels in excess of 6 dB. Due to their inherent lateral noise asymmetry, 3.3.2.2 of Chapter 3 of the Annex specifies that for propeller-driven aeroplanes simultaneous measurements be made at each and every test noise measurement point at its symmetrical position on the opposite side of the flight track.

GM A2 9.4.1
[Integrated procedure adjustments]

(1) Integrated procedure adjustments

3.3.1.1 provides details of an approved integrated adjustment method when the aeroplane is operated at stabilized flight path and thrust (power) conditions during the noise measurement period. Measured and reference flight paths are illustrated in Figure A2-15a and A2-15b of Appendix 2 of the Annex.

GM A2 9.4.2
[Emission angles]

(1) Emission Angles

For the integrated method, each one-half second noise data record will define a separate noise emission angle. This angle will then define the location of each data record along the reference flight path. The distance between consecutive data records along the reference flight path divided by the reference path speed provides the time interval between reference data records. The reference duration of each of these data records can be determined by obtaining the average of the two intervals between the adjacent data records. This may be different than 0.5s. Section 3.3.1.1.4 provides methods for time interval computations using the integrated method.

3.2 EQUIVALENT PROCEDURES INFORMATION

3.2.1 Subsonic jet aeroplanes

3.2.1.1 *Flight test procedures*

The following methods have been used to provide equivalent results to procedures described in Chapters 3 and 4 of the Annex for jet aeroplanes.

3.2.1.1.1 Flight path intercepts

Flight path intercept procedures, in lieu of full take-off and/or landing profiles described in 9.2 of Appendix 2 of the Annex have been used to meet the demonstration requirements for noise certification. The intercept procedures have also been used in the implementation of the generalized flight test procedures described in 3.2.1.1.2. The use of intercepts eliminates the need for actual take-offs and landings, with significant cost and operational advantages at high gross mass, and substantially reduces the test time required. Site selection problems are reduced and the shorter test period provides a higher probability of stable meteorological conditions during testing. Aeroplane wear and fuel consumption are reduced, while greater consistency and quality in noise data are obtained.

3.2.1.1.1.1 *For take-off*

Figure 3-20a illustrates a typical take-off profile. The aeroplane is initially stabilized in level flight at a point A and continues to point B where take-off power is selected and a steady climb is initiated. The steady climb condition is achieved at point C, intercepting the reference take-off flight path and continuing to the end of the noise certification take-off flight path. Point D is the theoretical take-off rotation point used in establishing the reference flight path. If thrust (power) reduction is employed, point E is the point of application of thrust (power) reduction and point F, the end of the noise certification take-off flight path. The distance TN is the distance over which the position of the aeroplane is measured and synchronized with the noise measurement at point K.

3.2.1.1.1.2 *For approach*

The aeroplane usually follows the planned flight trajectory while maintaining a constant configuration and power until there is no influence on the noise levels within 10 dB of maximum tone corrected perceived noise level (PNLTM). The aeroplane then carries out a go-around rather than continuing the landing (see Figure 3-20b).

For the development of the noise-power-distance (NPD) data for the approach case, the speed and approach angle constraints imposed by 3.6.3, 3.7.5, 4.5 and 4.6 of Chapters 3 and 4 of the Annex cannot be satisfied over the typical ranges of thrust (power) needed. For the approach case, a steady speed of V_{REF} + 19 km/h (V_{REF} + 10 kt) should be maintained to within ± 9 km/h (± 5 kt) and the height over the microphone should be 120 ± 30 m (394 ± 100 ft). Within these constraints the test approach angle at the test thrust (power) should be that resulting from the test aircraft conditions (i.e. mass, configuration, speed and thrust (power)).

The flight profiles should be consistent with the test requirements of the Annex over a distance that corresponds at least to noise levels that are 10 dB below the PNLTM (i.e. throughout the 10 db-down period) obtained at the measurement points during the demonstration.

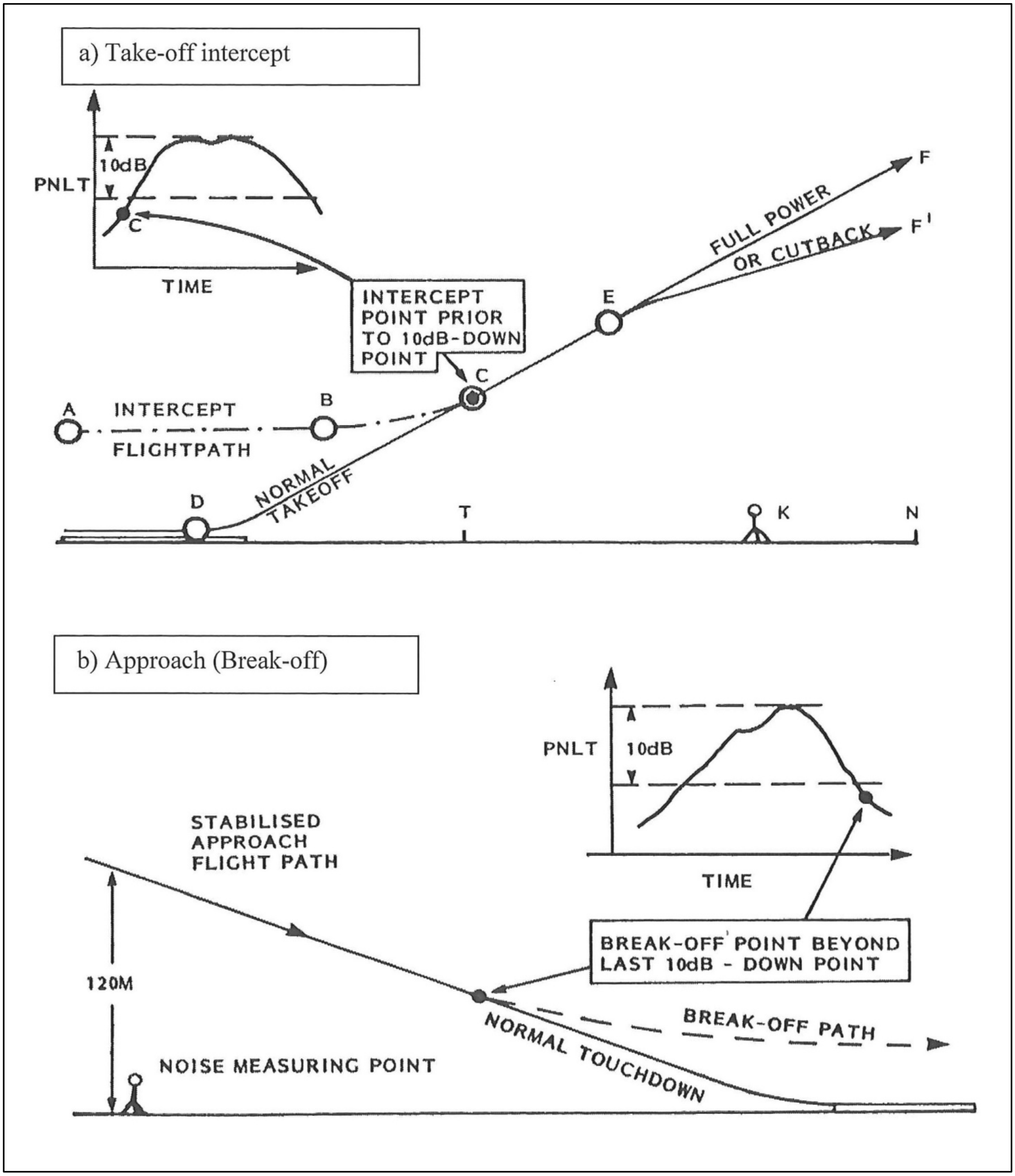


Figure 3-20 Flight path intercept procedures

3.2.1.1.2 Generalized flight test procedures

The following equivalent flight test procedures have been used for noise certification compliance demonstrations.

3.2.1.1.2.1 *For derivation of noise-power-distance (NPD) data*

For a range of thrusts (powers) covering full take-off and reduced thrusts (powers), the aeroplane is flown past lateral and under-flight-path microphones according to either the take-off procedures defined in 3.6.2 and 4.5 of Chapters 3 and 4 of the Annex or, more typically, the equivalent flight path intercept procedures described above in 3.2.1.1.1. Target test conditions are established for each sound measurement. These target test conditions define the flight procedure, the aerodynamic configuration to be selected, aeroplane mass, power, airspeed and the height at the closest point of approach to the measurement location. Regarding choice of target airspeeds and variation in test masses, the possible combinations of these test elements may affect the aeroplane angle-of-attack or aeroplane attitude and therefore possibly the aeroplane sound generation or propagation geometry.

The aeroplane angle-of-attack will remain approximately constant for all test masses if the tests are conducted at take-off reference airspeed appropriate for each test mass. For example, if the appropriate take-off reference airspeed for the aeroplane is $V_2+15\ kt$, then by setting the target airspeed at the $V_2+15\ kt$ appropriate for each test mass, while the actual airspeed will vary according to each test mass the aeroplane test angle-of-attack will remain approximately constant. Alternatively, for many aeroplanes the aeroplane attitude remains approximately at the attitude associated with the take-off reference airspeed corresponding to the maximum take-off mass. Review of these potential aeroplane sensitivities may dictate the choice of target airspeeds and/or test masses in the test plan in order to limit excessive changes in angle-of-attack or aeroplane attitude that could significantly change measured noise data. In the execution of each condition, the pilot should "set up" the aeroplane in the appropriate condition in order to pass by the noise measurement location within the target height window, while maintaining target power and airspeed, within agreed tolerances, throughout the 10 dB-down period.

A sufficient number of noise measurements are made in order to establish noise-power curves at a given distance for both lateral and flyover cases These curves are extended either by calculation or by the use of additional flight test data to cover a range of distances, to form the generalized noise database for use in the noise certification of the "flight datum" and derived versions of the aeroplane type and are often referred to as Noise-Power-Distance (NPD) plots (see Figure 3-21). If over any portion of the range for the NPD plot, the criteria for calculating the Effective Perceived Noise Level (EPNL) given in 9.1.2 of Appendix 2 of the Annex requires the use of the integrated procedure, then this procedure shall be used for the whole NPD plot. The 90 per cent confidence intervals about the mean lines are constructed through the data (see 2.5).

Note.- The same techniques may be used to develop NPD plots that are appropriate for deriving approach noise levels by flying over an under-flight-path microphone for a range of approach powers, using the speed and aeroplane configuration given in 3.6.3 and 4.5 of Chapters 3 and 4 of the Annex or more typically, the flight test procedures described in 3.2.1.1.1.2.

The availability of flight test data for use in data adjustment (e.g. speed and height) should be considered in test planning as such availability may limit the extent to which a derived version may be certificated without further flight testing, especially where the effects of airspeed on source noise levels become significant. The effects of high altitude test site location on jet noise source levels should also be considered in test planning. High altitude test site locations have been approved under conditions specified in 3.3.2.3, provided that jet noise source adjustments are applied to the noise data. The correction method described in 3.3.2.3 has been approved for this purpose.

Flyover, lateral and approach noise measurements should be corrected to the reference speed and atmospheric conditions over a range of distances in accordance with the procedures described in Appendix 2 of the Annex. NPD plots can then be constructed from the adjusted EPNL, power and distances. These plots present the EPNL values for a range of distance and engine noise performance parameters.

The parameters are usually the corrected low pressure rotor speed ($N_1/\sqrt{\theta_{t_2}}$) or the corrected net thrust (F_N/δ_{amb}) (see Figure 3-21), where:

- N_1 is the actual low pressure rotor speed;
- θ_{t_2} is the ratio of the absolute static temperature of the air at the height of the aeroplane to the absolute temperature of the air for an International Standard Atmosphere (ISA) at mean Sea Level (i.e. 288.15 K);
- F_N is the actual engine net thrust (power) per engine; and
- δ_{amb} is the ratio of the absolute static pressure of the ambient air at the height of the aeroplane to ISA air pressure at mean Sea Level (i.e. 101.325 kPa).

Generalized NPD data may be used in the certification of the flight tested aeroplane and derivative versions of the aeroplane type. For derived versions, these data may be used in conjunction with analytical procedures, static testing of the engine and nacelle, or additional limited flight tests to demonstrate compliance.

3.2.1.1.2.2 *For flight test procedures for determination of changes in aeroplane certification noise levels*

Noise level changes determined by comparison of flight test data for different configurations of an aeroplane type have been used to establish certification noise levels of newly derived versions by reference to the noise levels of the "flight datum" aeroplane. These noise level changes are added to or subtracted from the noise levels obtained from individual flights of the 'flight datum' aeroplane. Confidence intervals of new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see 2.5).

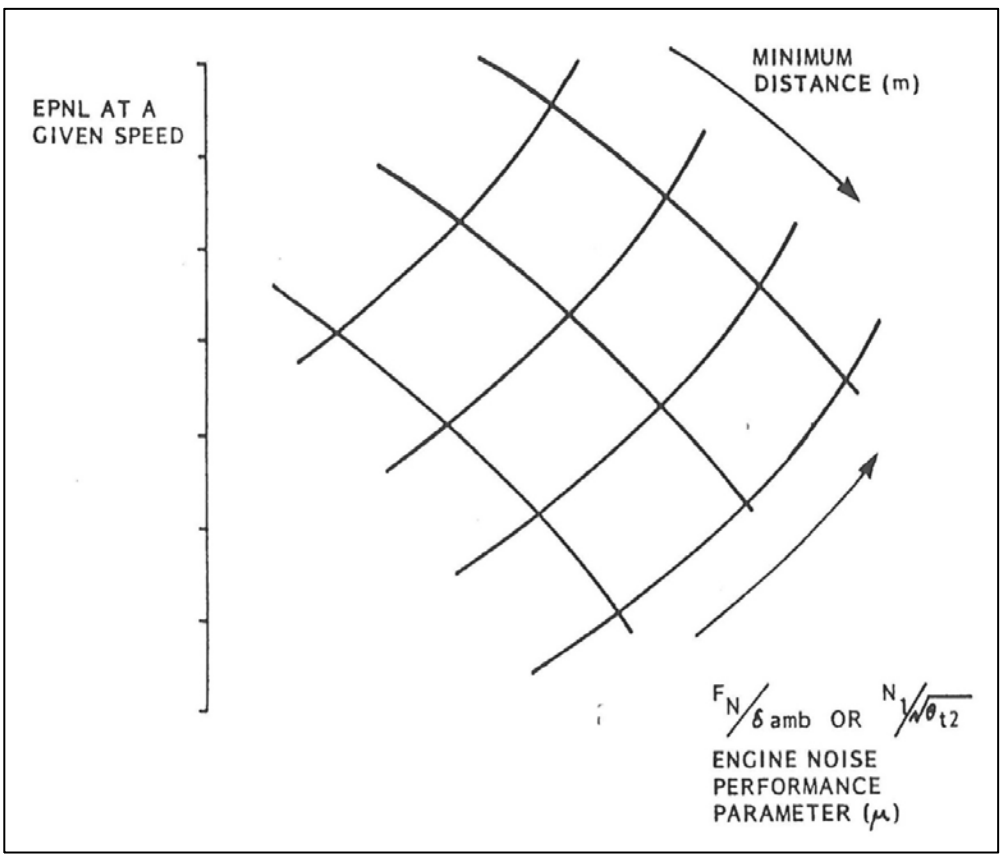


Figure 3-21 Form of noise-power-distance (NPD) plot for jet powered aeroplane

3.2.1.1.3 Determination of the lateral noise certification levels

The lateral full-power reference noise measurement point for jet-powered aeroplanes is defined as the point on a line parallel to and 450 m (1476 ft) from the runway centre line, where the noise level is a maximum during take-off. Alternative procedures using two microphone stations located symmetrically on either side of the take-off reference track have proven to be effective in terms of time and costs savings. Such an arrangement avoids many of the difficulties encountered when using multiple microphone arrays along the lateral lines. The procedure consists of flying the test aeroplane at full take-off thrust (power) at several different specified heights above a track at right angles to and midway along the line joining the two microphone stations. When this procedure is used, matching data from both lateral microphones for each fly-past should be used for the lateral noise determination. Fly-pasts where data from only one microphone is available must be omitted from the determination. The following paragraphs describe this equivalent procedure for determining the lateral noise level for jet aeroplanes.

a) For aeroplanes being certificated under Chapters 3 and 4 of the Annex two microphone locations are typically used, symmetrically placed on either side of, and 450 m (1476 ft) from the aeroplane reference flight track.

b) Fly-pasts are performed at constant full take-off power, configuration and airspeed as described in 3.6.2c and 3.6.2d of Chapter 3 and 4.5 of Chapter 4 of the Annex.

c) The aeroplane should be flown along a track that intersects at right angles the line joining the two microphones. A number of flights should be performed such that the height of the aeroplane as it crosses this line typically covers a range between 60 m and 600 m (approximately between 200 ft and 2000 ft).

d) Adjustment of measured noise levels should be made to the acoustical reference day conditions and to reference aeroplane operating conditions as specified in section 9 of Appendix 2 of the Annex.

e) If the adjusted noise levels show a reasonable degree of symmetry between the left and right sides, as will generally be the case for jet aeroplanes, the arithmetic average of the EPNLr values for the lateral microphone pair should be plotted against either the height of the aeroplane opposite the microphones or the average of the acoustic emission heights for PNLTM. A regression curve, which is typically second order, is plotted through the data points. The reported lateral Effective Perceived Noise Level at the reference condition needed for the purpose of demonstrating compliance with the applicable noise limit is the maximum value of the curve.

f) For aeroplanes for which the adjusted noise levels exhibit a marked degree of asymmetry the EPNLr values for the left and right side should be plotted against either the height of the aeroplane opposite the microphone location or the height at the time of emission of PNLTM. Separate regression curves, which are typically second order, are plotted through the data points for the left and right sides. The reported lateral Effective Perceived Noise Level at the reference condition (EPNLr) needed for the purpose of demonstrating compliance with the applicable noise limit is the maximum value of the curve midway between the left and right curves.

g) It should also be established that the confidence interval associated with the reported lateral Effective Perceived Noise Level (i.e. the maximum “regression” value of EPNLr) is within the ± 1.5 dB 90 per cent confidence interval specified in 5.4 of Appendix 2 of the Annex (see 2.5.2.2).

Note.- Exceptionally and in order to obtain a curve from which a maximum value can be clearly determined either a third order regression curve or the removal from the analysis of some outlying data points might be permitted. Applicants will be required to provide technical justification for the use of such exceptional procedures which will be subject to the approval of the certificating authority.

Certification lateral noise levels have also been determined by using multiple pairs of laterally opposed microphones rather than only one pair. In this case the microphones must be sufficiently spaced along the lateral line to ensure that the noise levels measured at each microphone are statistically independent. A sufficient number of data points, resulting from a minimum of six runs, must be obtained in order to adequately define the maximum lateral

EPNLr value and provide an acceptable 90 per cent confidence interval.

Lateral noise measurements for a range of conventionally configured aeroplanes with under wing and/or rear-fuselage mounted engines having a bypass ratio of more than two have shown that the maximum lateral noise at full power normally occurs when the aeroplane is close to 300 m (984 ft) in height during the take-off. Based on this finding and subject to the approval of the certificating authority the aeroplane may be flown on a minimum of six acceptable occasions such that it passes the microphone stations at a target height of 300 m (984 ft) and be no more than +100 m, -50 m (+328 ft, –164 ft) relative to this target height.

3.2.1.1.4 Take-off flyover noise levels with thrust (power) reduction

Flyover noise levels with thrust (power) reduction may also be established without making measurements during take-off with full thrust (power) followed by thrust (power) reduction (see 3.2.1.2.1 for details).

3.2.1.1.5 Measurements at non-reference points

In some instances test measurement points may differ from the reference measurement points specified in 3.3.1 and 4.3 of Chapters 3 and 4 of the Annex. Under these circumstances an applicant may request approval of data that have been adjusted from actual measurements in order to represent data that would have been measured at the reference noise measurement points at reference conditions.

Reasons for requesting approval of such adjusted data may be:

a) to allow the use of a measurement location that is closer to the aeroplane flight path so as to improve data quality by obtaining a greater ratio of signal to background noise. Whereas 2.6.3 describes a procedure for removing the effects of background noise, the use of data collected closer to the aeroplane avoids the interpolations and extrapolations inherent in the method;

b) to enable the use of an existing, approved noise certification database for an aeroplane type design in the certification of a derivative of that type, when the derivative is to be certificated under reference conditions that differ from the original type certification reference conditions; and

c) to avoid obstructions near the noise measurement points which could influence sound measurements. When a flight path intercept technique is being used, flyover and approach noise measurement points may be relocated as necessary to avoid undesirable obstructions. Lateral noise measurement points may be relocated by distances which are of the same order of magnitude as the aeroplane lateral deviations or offsets relative to the nominal flight paths that occur during flight testing.

Approval has been granted to applicants for the use of data from non-reference noise measurement points provided that measured data are adjusted to reference conditions in accordance with the requirements of section 9 of Appendix 2 of the Annex and the magnitudes of the adjustments do not exceed the limitations cited in 3.7.6 and 4.6 of Chapters 3 and 4 of the Annex.

3.2.1.1.6 Atmospheric test conditions

Certificating authorities have found it acceptable to exceed the sound attenuation coefficient limits of 2.2.2.2c of Appendix 2 of the Annex in cases when:

a) the dew point and dry bulb temperature are measured with a device which is accurate to ± 0.5 °C and are used to obtain relative humidity, and when “layered” sections of the atmosphere are used to compute sound attenuation coefficients in each one-third octave band in compliance with the provisions of 2.2.2.4 of Appendix 2 of the Annex; or

b) the peak noy values at the time of tone corrected perceived noise level (PNLT), after adjustment to reference conditions, occur at frequencies of less than or equal to 400 Hz.

3.2.1.1.7 Layering Equivalency

Section 2.2.2 of Appendix 2 of the Annex defines the procedure for layering the atmosphere and determining the sound attenuation coefficients to be used in the adjustment of the aircraft noise levels. The procedure requires that "the atmosphere from the ground to at least the height of the aeroplane shall be divided into layers of 30 m (100 ft) depth". Subject to the approval of the certificating authority the applicant may use layers of more or less, and not necessarily equal, depth. The applicant should demonstrate that the layering procedure being proposed is equivalent to the procedure defined in the Annex.

3.2.1.2 ***Analytical procedures***

Analytical equivalent procedures rely upon available noise and performance data obtained from flight test for the aeroplane type. Generalized relationships between noise, power and distance (see 3.2.1.1.2.1 for derivation of NPD plots) and adjustment procedures for speed changes in accordance with the methods of Appendix 2 of the Annex are combined with certificated aeroplane aerodynamic performance data to determine noise level changes resulting from type design changes. These noise level increments are then applied to noise levels in accordance with 3.2.1.1.2.

3.2.1.2.1 Flyover noise levels with thrust (power) reduction

Flyover noise levels with thrust (power) reduction may be established from the merging of PNLT versus time measurements obtained during constant power operations. As illustrated in Figure 3-22a, the 10 dB-down PNLT noise time history recorded at the flyover point may contain portions of both full thrust (power) and reduced thrust (power) noise time histories. As long as these noise time histories, the average engine spool-down thrust (power) characteristics, and the aeroplane flight path during this period (see Figure 3-22b), which includes the transition from full to reduced thrust (power), are known, the flyover noise level may be computed.

Where the full thrust (power) portion of the noise time history does not intrude upon the 10 dB-down time history of the reduced thrust (power), the flyover noise levels may be computed from a knowledge of the NPD characteristics and the effect of the average spool-down thrust (power) characteristics on the aeroplane flight path.

Note 1.- The selection of the height of an aeroplane within the reference flight path for initiation of thrust (power) reduction should take into account both the "average engine" spool-down time and a 1.0 s delay for flight crew recognition and response prior to movement of the throttles to the reduced thrust (power) position.

Note 2.- To ensure that the full thrust (power) portion of the noise time history does not intrude upon the 10 dB-down noise levels,

$$\underset{After\,cutback}{PNLTM} - \underset{Before\,cutback}{PNLT} \geq 10.5\,dB$$

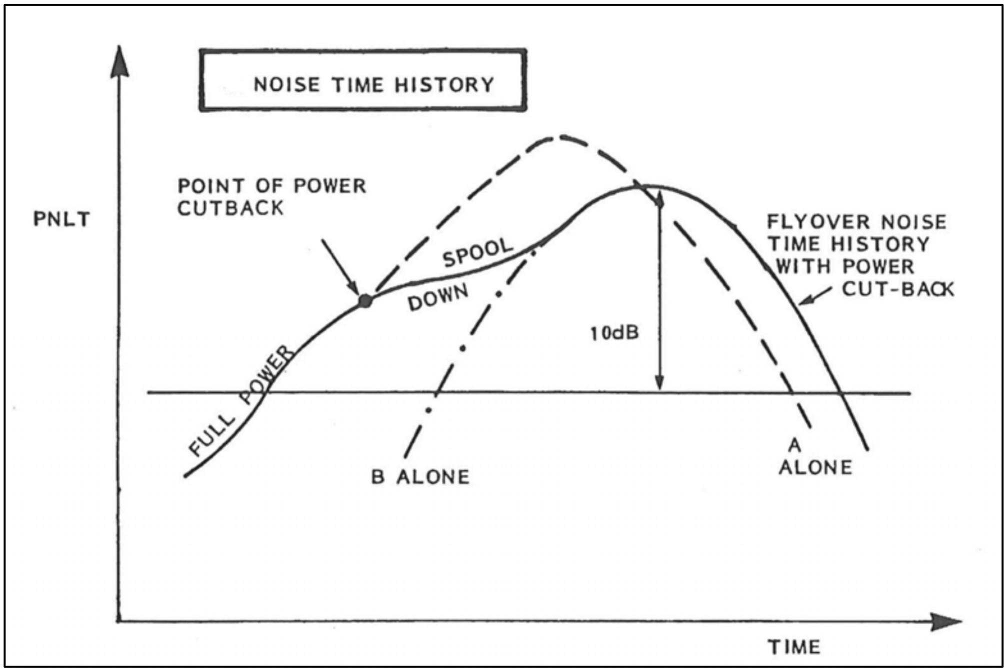


Figure 3-22a Computation of cutback take-off noise level from constant power tests

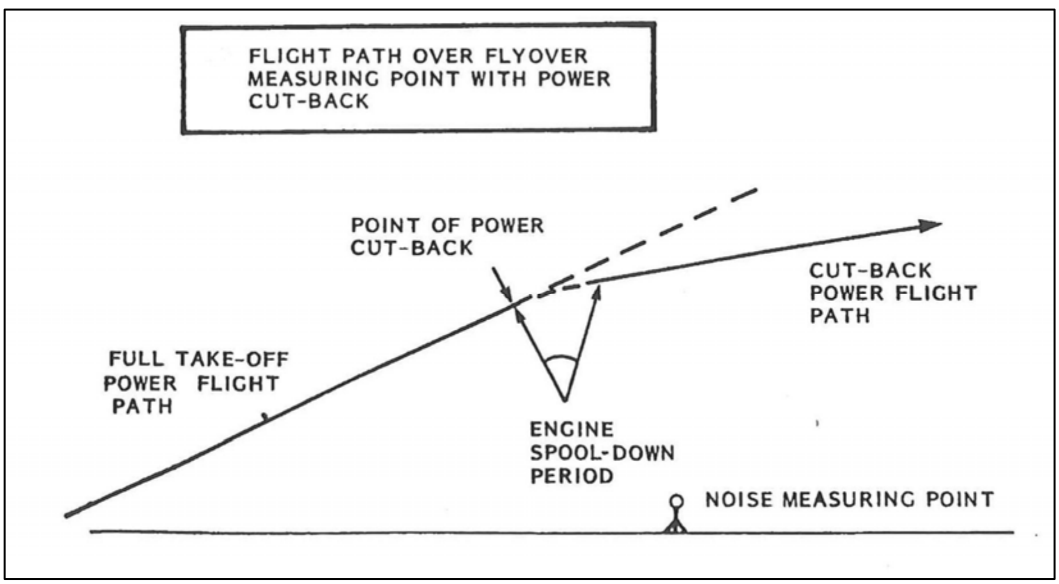


Figure 3-22b Computation of reduced thrust take-off noise level from constant thrust tests

3.2.1.2.2 Equivalent procedures based upon analytical methods

Noise certification approval has been given for applications based on type design changes that result in predictable noise level differences, including the following:

a) Changes to the originally certificated take-off or landing mass which in turn lead to changes in the distance between the aeroplane and the microphone and/or reduced thrust (power) for the take-off case, and changes to the approach power. In this case the NPD data may be used to determine the noise certification level of the derived version;

b) Noise changes due to engine power changes. However, care should be taken to ensure that when NPD plots are extrapolated, the relative contribution of the component noise sources to the EPNL remains essentially unchanged and a simple extrapolation of the NPD curves can be made. Among the items which should be considered in extending the NPD are:

   – the 90 per cent confidence interval at the extended thrust (power);

   – aeroplane/engine source noise characteristics and behaviour;

   – engine cycle changes; and

   – quality of data to be extrapolated.

c) aeroplane engine and nacelle configuration and acoustical treatment changes, usually leading to changes in the values of EPNLr of less than 1 dB;

   Note.- It should however be ensured that new noise sources are not introduced by modifications made to the aeroplane, engine or nacelles. A validated analytical noise model approved by the certificating authority may be used to derive predictions of noise increments. The analysis may consist of modelling each aeroplane component noise source and projecting the sources to flight conditions in a manner similar to the static test procedure described in 3.2.1.3. A model of detailed spectral and directivity characteristics for each aeroplane noise component may be developed by theoretical and/or empirical analysis. Each component should be correlated to the parameters which relate to the physical behaviour of source mechanisms. The source mechanisms, and subsequently the correlating parameters, should be identified through use of other supplemental tests such as engine or component tests. As described in 3.2.1.3, an $EPNL_r$ *value representative of flight conditions should be computed by adjusting aeroplane component noise sources for forward speed effects and for the number of engines and shielding, reconstructing the total noise spectra, and projecting the total noise spectra to flight conditions by accounting for propagation effects. The effect of changes in acoustic treatment, such as nacelle lining, may be modelled and applied to the appropriate component noise sources. The computation of the total noise increments, the development of the changed version NPD, and the evaluation of the changed version* $EPNL_r$ *values should be made by using the procedures described in 3.2.1.3.4. Guidance material on confidence interval computations is provided in 2.5.*

d) airframe design changes (e.g. changes in fuselage length, flap configuration and engine installation) that could indirectly affect noise levels because of an effect on aeroplane performance (e.g. increased drag).

   Note 1.-Changes in aeroplane performance characteristics derived from aerodynamic analysis or testing have been used to demonstrate how these changes affect the aeroplane flight path and hence the demonstrated noise levels of the aeroplane.

   Note 2.-In these cases care should be exercised to ensure that the airframe design changes do not introduce significant new noise sources nor modify existing source generation or radiation characteristics. In such instances the magnitude of such effects may have to be established by test.

3.2.1.2.3 Equivalent procedure for calculating the certification noise levels of weight variants of a given aeroplane type

Section 1.2 of Chapter 1 of the Annex 16 specifies that "Noise certification shall be granted or validated by the State of Registry of an aircraft on the basis of satisfactory evidence that the aircraft complies with the requirements that are at least equal to the applicable Standards in this Annex". The lateral, flyover and approach noise levels and their 90 per cent confidence intervals for the weight variants of a given aeroplane/engine model and acoustic configuration are typically derived from generalized Noise Power Distance (NPD) curves, based on the information in noise certification reports and supporting documentation, and in conjunction with certificated aerodynamic performance data for the aeroplane, as approved by the certification authorities.

Some aeroplane manufacturers have used the noise level information initially certificated for several weight variants to demonstrate that when the basic aeroplane performance parameters (e.g. V_2 and V_{ref}) vary in a linear manner over a range of certificated takeoff or approach weights, the resulting noise (EPNL) versus weight relationship can be shown to be linear in that range as well. When this situation is demonstrated by the applicant, and subject to the approval of the certificating authority, the applicant may derive the certification noise levels of additional weight variants using linear interpolation between previously certificated points. The confidence interval for the interpolated weight is then to be established in a process that utilizes the polynomial regression models that had been used by the applicant to develop the NPD. For a given aeroplane type, equivalency of the interpolated noise level values is demonstrated when the noise levels and the associated confidence intervals are calculated and reported in a manner acceptable to the certificating authority.

3.2.1.3 *Static engine noise tests and projections to flight noise levels*

3.2.1.3.1 General

Static engine noise test data provide valuable definitive information for deriving the noise levels that result from changes to an aeroplane powerplant or from the installation of a broadly similar powerplant into the airframe following initial noise certification of the "flight datum" aeroplane. This involves the testing of both the "flight datum" and derivative powerplants using an open-air test facility where the effect on the noise spectra of the engine modifications on aeroplane noise characteristics may be assessed. It can also extend to the use of component test data to demonstrate that when minor development changes have been made the noise levels remain unchanged (i.e. a No-Acoustical Change, NAC).

Approval of equivalent procedures for the use of static engine noise test data depends critically upon the availability of an adequate approved database (NPD plot) acquired from the flight testing of the "flight datum" aeroplane.

Static engine noise tests can provide sufficient additional data or noise source characteristics to allow for predictions about the effect of changes on the aeroplane noise certification levels

Types of static tests accepted for the purposes of certification compliance demonstration in aeroplane development include engine noise tests. Such tests are useful for assessing the effects of mechanical and thermodynamic cycle changes to the engine on the individual noise sources. Such configuration and/or design changes often occur as engines are developed subsequent to the initial noise certification of an aircraft to ease production difficulties, reduce cost, improve durability, and for operational reasons

Static engine noise testing is discussed in detail in subsequent sections. For component tests, the criteria for acceptability are less definable. There are many instances, particularly when only small changes in $EPNL_r$ are expected, where component testing will provide an adequate demonstration of noise impact.

Examples of such changes include:

a) changes in the specification of sound-absorbing linings within an engine nacelle;

b) changes in the mechanical or aerodynamic design of the fan, compressor or turbine;

c) changes to combustor designs, including material changes;

d) changes to bleed valves; and

e) changes to exhaust system.

Each proposal by an applicant to use component test data should be considered by the certificating authority with respect to the significance of the relevant affected source on the values of $EPNL_r$ for the aeroplane that is being certificated.

3.2.1.3.2 Limitation on the projection of static to flight data

Guidance on the acceptability, use and applicability of static engine test data are contained in subsequent sections.

The amount by which the measured noise levels of a derivative engine will differ from those of the reference engine is a function of several factors, including:

a) thermodynamic changes to the engine cycle, including increases in thrust (power);

b) design changes to major components (e.g. the fan, compressor, turbine, exhaust system, etc.); and

c) changes to the nacelle.

Additionally, day-to-day and test-site-to-test-site variables can influence measured noise levels and therefore the test, measurement and analysis procedures described in this Manual are designed to account for these effects. A limit is needed that can be used uniformly by certificating authorities in order that the degree of change resulting from aspects such as a), b) and c), when extrapolated to flight conditions, is restricted to acceptable amounts before a new flight test is required.

The recommended guideline for this limit is that the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the "flight datum" aeroplane and the derived version at the same thrust (power) and distance for the derived version is no greater than 5 EPNdB, with a maximum of 3 EPNdB at any one of the reference conditions (see Figure 3-23). For differences greater than this, additional flight testing at conditions where noise levels are expected to change is recommended in order to establish a new flight NPD database.

Provided that the detailed prediction procedures used are verified by flight test for all the types of noise sources (i.e. tones, non-jet broadband and jet noise relevant to the aeroplane under consideration) and that there are no significant changes in installation effects between the aeroplane used for the verification of the prediction procedures and the aeroplane under consideration, the procedure may be employed without the limitations described above.

In addition to the limitations described above, a measure of acceptability regarding methodologies for static-to-flight projection is also needed for uniform application by certificating authorities. This measure can be derived as the residual NPD differences between the flight test data and the projected static-to-flight data for the original aeroplane version. The guideline for a measure of acceptability is to limit these residual differences to 3 EPNdB at any one of the reference conditions.

In determining the noise levels of the modified or derived version, the same analytical procedures used in the first static-to-flight calculations for the noise certification of the aeroplane type shall be used.

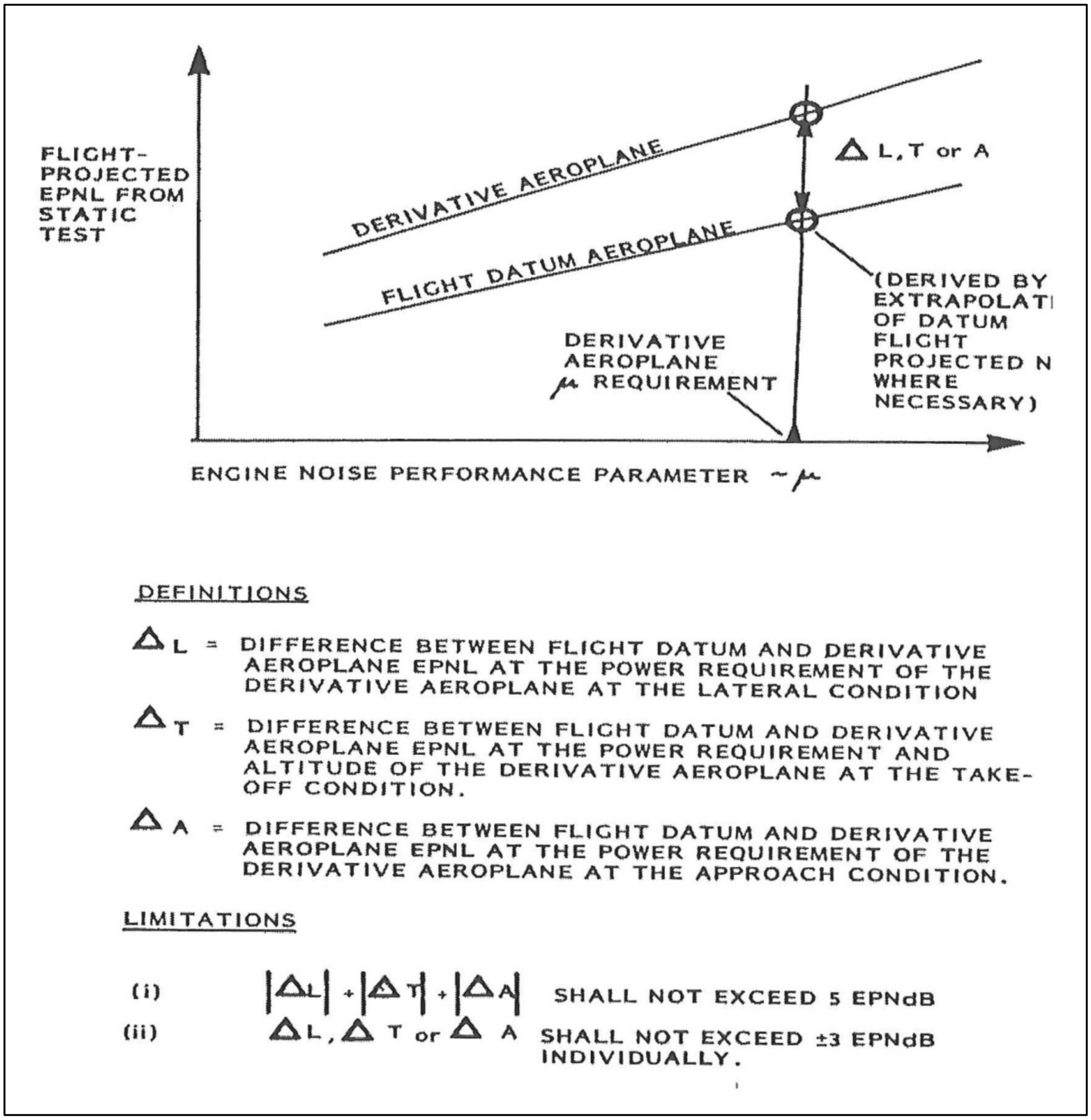


Figure 3-23 Limitation on use of static test when no validating flight data exist

3.2.1.3.3 Static engine noise test procedures

3.2.1.3.3.1 *General*

This section provides guidelines on static engine test data acquisition, analysis and normalization techniques. The information provided may be used in conjunction with guidelines for test site, measurement and analysis systems and test procedures provided in Reference 10.

Noise data acquired from static tests of engines with similar designs to those that were flight tested may be projected, when appropriate, to flight conditions. Once approved, noise data acquired from static tests may be used to supplement an approved NPD plot for the purpose of demonstrating compliance with the Annex provisions in support of a change in type design. The engine designs, as well as the test and analysis techniques to be used, should be presented in the test plan and submitted, for approval, to the certificating authority for concurrence prior to testing.

Test restrictions defined for flight testing in conformity with the Annex are not necessarily appropriate for static testing (Reference 10 provides appropriate guidance). For example, the measurement distances associated with static tests are substantially less than those encountered in flight testing and may permit testing in atmospheric conditions not otherwise permitted by the Annex for flight testing. Moreover, since static engine noise is a steady sound pressure level rather than the transient noise level of a flyover, the measurement and analysis techniques may be somewhat different for static noise testing.

3.2.1.3.3.2 *Test site requirements*

The test site should meet at least the criteria specified in Reference 10. Different test sites may be selected for testing different engine configurations, provided the noise measurements from the different sites can be adjusted to a common reference condition.

3.2.1.3.3.3 *Engine inlet bellmouth*

The installation of a bellmouth forward of the engine inlet may be used with jet engines during static engine noise tests. Such an installation is used to provide a simulated flight condition of inlet flow during static testing. Production inlet acoustic lining and spinners are also to be installed during noise testing.

3.2.1.3.3.4 *Inflow control devices (ICD)*

Static engine noise test noise data for the noise certification of an aeroplane with a change of engine to another one of a similar design should be acquired by using an approved Inflow Control Device (ICD) for high bypass engines (i.e. BPR > 2.0). The ICD should meet the following requirements:

a) The specific ICD hardware must be inspected by the certificating authority to ensure that the ICD is free from damage and contaminants that may affect its acoustic performance;

g) The ICD must be acoustically calibrated by an approved method (see 3.2.1.3.3.5) to determine its effect on sound transmission in each one-third octave band;

h) Data obtained during static engine noise testing must be adjusted to account for sound transmission effects that are caused by the ICD. The adjustments shall be applied to each one-third octave band of data measured;

i) The ICD position relative to the engine inlet lip must be determined and the calibration must be applicable to that position;

j) No more than one calibration is required for an ICD hardware design, provided that there is no deviation from the design for any one ICD serial number hardware set.

It is not necessary to apply the ICD calibration adjustments if the same ICD hardware (i.e. identical serial number) that was previously used in the static engine noise test of the flight engine configuration is used, and the fan tones for both engines remain in the same one-third octave bands.

3.2.1.3.3.5 *ICD calibration*

An acceptable ICD calibration method is as follows:

a) Place an acoustic driver(s) on a simulated engine centre line in the plane of the engine inlet lip. Locate the calibration microphones on the forward quadrant azimuth at a radius between 15 m (50 ft) and 45 m (150 ft) that provides a good signal-to-ambient noise ratio and also at each microphone angle to be used to analyse static engine noise data. Locate a reference near-field microphone on the centre line of and within 0.6 m (2 ft) of the acoustic centre of the acoustic driver(s);

b) Energize the acoustic driver with pink noise without the ICD in place. Record the noise for a minimum of 60s duration following system stabilization. The procedure must be conducted at a constant input voltage to the acoustic driver(s);

c) Repeat item b), alternately with and without the ICD in place. A minimum of three tests of each configuration with and without ICD in place is required. To be acceptable, the total variation of the 55° microphone on-line OASPL signal, averaged for a 1-minute duration, for all three test conditions of each configuration, shall not exceed 0.5 dB;

Note.- Physically moving the ICD alternately in and out of place for this calibration may be eliminated if it is demonstrated that the ICD positioning does not affect the calibration results.

d) All measured data are to be adjusted for sound pressure level variations, as measured with the near-field microphone and, for atmospheric absorption to 25°C (77°F) and 70 per cent relative humidity (RH) conditions by using the slant distance between the outer microphones and the acoustic driver(s);

e) The calibration for each one-third octave band at each microphone is the difference between the average of the adjusted one-third octave band sound pressure levels (SPL) without the ICD in place and the average of the adjusted one-third octave band sound pressure levels with the ICD in place; and

f) The tests must be conducted under wind and thermal conditions that preclude acoustic shadowing at the outer microphones and weather-induced variations in the measured sound pressure level data (see Figure 3-24).

In some cases large fluctuations in the value of the calibrations across adjacent one-third octave bands and between closely spaced angular positions of microphones can occur. These fluctuations can be related to reflection effects caused by the calibration procedure and care must be taken to ensure that they do not introduce or suppress engine tones. This may be done by comparing EPNL computed with:

a) the ICD calibrations as measured;

b) a mean value of the calibration curves; and

c) the calibration values set to zero.

3.2.1.3.3.6 *Measurement and analysis systems*

Measurement and analysis systems used for static test and the modus operandi of the test program may well vary according to specific test objectives. In general they should conform with those outlined in Reference 10. Some important factors to be taken into account are highlighted in subsequent sections.

3.2.1.3.3.7 *Microphone locations*

Microphones should be located over an angular range sufficient to include the 10 dB-down times after projection of the static noise data to flight conditions. The general guidance in Reference 10 describing microphone locations is sufficient to ensure adequate definition of the engine noise source characteristics.

The choice of microphone location with respect to the test surface depends on the specific test objectives and the methods to be used for data normalization. Certification experience with static engine testing has been primarily limited to microphone installations near the ground or at engine centre line height. In general, because of the difficulties associated with obtaining free-field sound pressure levels that are often desirable for extrapolating to flight conditions, near-ground-plane microphone installations or a combination of ground-plane and elevated microphones have been used. Consistent microphone locations, heights etc. are recommended for noise measurements of both the prior approved and changed version of an engine or nacelle.

3.2.1.3.3.8 *Acoustic shadowing*

Where ground plane microphones are used, special precautions are necessary to ensure that consistent measurements (e.g. free from "acoustic shadowing" refraction effects) will be obtained. When there is a wind in the opposite direction to the sound wave propagating from the engine, or when there is a substantial thermal gradient in the test arena, refraction can influence near ground plane microphone measurements to a larger degree than measurements at greater heights.

Previous evidence, or data from a supplemental test, may be used to demonstrate that testing at a particular test site results in consistent measurements, including the absence of shadowing. In lieu of this evidence a supplemental noise demonstration test should include an approved method to indicate the absence of shadowing effects for the ground-plane measurements.

The following criteria are suggested for certain test geometries, based on measurements of three weather parameters as follows:

a) Average wind speeds at engine centre line height (WCL);

b) Air temperature at engine centre line height (TCL); and

c) Air temperature at near ground plane microphone height (TMIC).

The criteria are:

a) The instruments for these measurements should be co-located and placed close to the 90° noise measurement position without impeding the acoustic measurement;

b) The suggested limits are additional to the wind and temperature limits established by other criteria such as the maximum wind speed at the microphone if wind screens are not used; and

c) Wind and temperature criteria that have been observed to provide consistent measurements that preclude any influence of acoustic shadowing effects on ground-plane measurements as defined in Figure 3-24).

Figure 3-24 defines a boundary between the absence of shadowing and the possible onset of spectral deficiencies in the very high frequencies. Testing is permitted provided that the test-day conditions are such that the average, typically 30 s, wind speed at engine centre line height falls below the line shown, and that wind gusts do not exceed the value of the line shown by more than 5.5 km/h (3 kt). Wind speeds in excess of the linear relationship shown, between 7 km/h and 22 km/h (4 kt and 12 kt), may indicate the need to demonstrate the absence of spectral abnormalities, either prior to or at the time of test, when the wind direction opposes the direction of sound propagation.

When the temperature at the height of the ground microphone is not greater than the temperature at the engine centre line height plus 4°C (39°F), shadowing effects due to temperature gradients can be expected to be negligible.

Note.- Theoretical analyses and the expression of wind criteria in terms of absolute speed rather than the vector reduction suggest that the limits described herein may be unduly stringent in some directions.

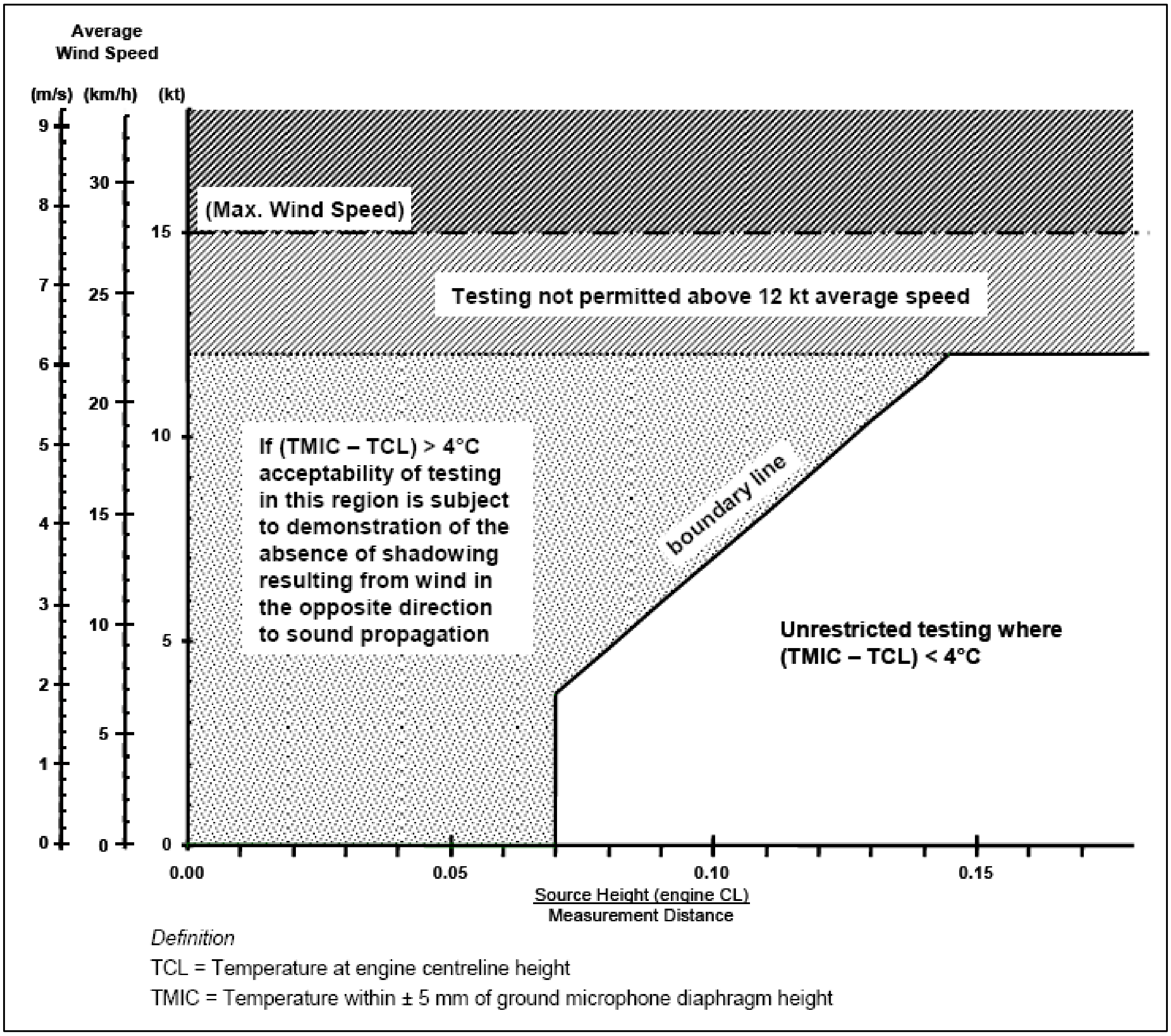


Figure 3- 24 Weather criteria for use with ground microphone installations

3.2.1.3.3.9 *Engine power test conditions*

A range of static engine operating conditions should be selected to correspond to the expected maximum range of in-flight engine operating conditions for the appropriate engine power setting parameter. A sufficient number of stabilized engine power settings over the desired range should be included in the test to ensure that the 90 per cent confidence intervals for values of flight-projected EPNL can be established (see 2.5.3).

3.2.1.3.3.10 *Data system compatibility*

If more than one data acquisition system and/or data analysis system is used for the acquisition or analysis of static data, compatibility of the airframe and engine manufacturers' systems is necessary. Compatibility of the data acquisition systems can be accomplished through appropriate calibration. Compatibility of the data analysis systems can be verified by analysing the same data samples on both systems. The systems are compatible if the resulting differences are no greater than 0.5 EPNdB. Evaluation should be conducted at flight conditions representative of those for certification.

The use of pseudo-random noise signals with spectral shape and tonal content representative of turbofan engines is an acceptable alternative to the use of actual engine noise measurements for determining analysis system compatibility. The systems are compatible if the resulting differences are no greater than 0.5 PNdB for an integration time of 32 s.

3.2.1.3.3.11 *Data acquisition, analysis and normalization*

For each engine power setting designated in the test plan, the engine performance, meteorological and sound pressure level data should be acquired and analysed using measurement systems and test procedures described in Reference 10 or as approved by the certificating authority.

Noise measurements should be normalized to consistent conditions and include 24 one-third octave band sound pressure levels between band centre frequencies of 50 Hz to 10 kHz for each measurement microphone. Before projecting the static engine data to flight conditions, the sound pressure level data should be adjusted for:

a) the frequency response characteristics of the noise measurement system; and

b) contamination by background or electrical system noise (see 2.6.3).

3.2.1.3.4 Projection of static engine data to aeroplane flight conditions

3.2.1.3.4.1 *General*

The static engine sound pressure level data acquired at each angular location should be analysed and normalized to account for the effects identified in the paragraphs below. They should then be projected to the same aeroplane flight conditions used in the development of the approved NPD plot.

As appropriate, the projection procedure includes:

a) the effects of source motion including Doppler effects;

b) the number of engines and shielding effects;

c) the installation effects;

d) the flight geometry;

e) the atmospheric propagation, including spherical wave divergence and sound attenuation; and

f) the flight propagation effects including ground reflection and lateral attenuation.

To account for these effects, the measured total static noise data should be analysed to determine contributions from individual noise sources. After projection of the one-third octave-band spectral data to flight conditions, EPNLs should be calculated for the revised NPD plot. Guidelines on the elements of an acceptable projection procedure are provided in this section. The process is also illustrated in the Figures 3-25 and 3-26.

It is not intended that the procedure illustrated in Figures 3-25 and 3-26 should be exclusive. There are several options, depending upon the nature of the powerplant noise sources and the relevance of individual noise sources to the EPNL of the aeroplane. The method presented does however specify the main features that should be considered in the computational procedure.

It is also not necessary that the computations illustrated in Figures 3-25 and 3-26 should always be carried out in the order specified. There are interrelations between the various steps in the procedure which depend on the particular form of the computation being followed. Hence the most efficient manner of structuring the computation cannot always be pre-determined.

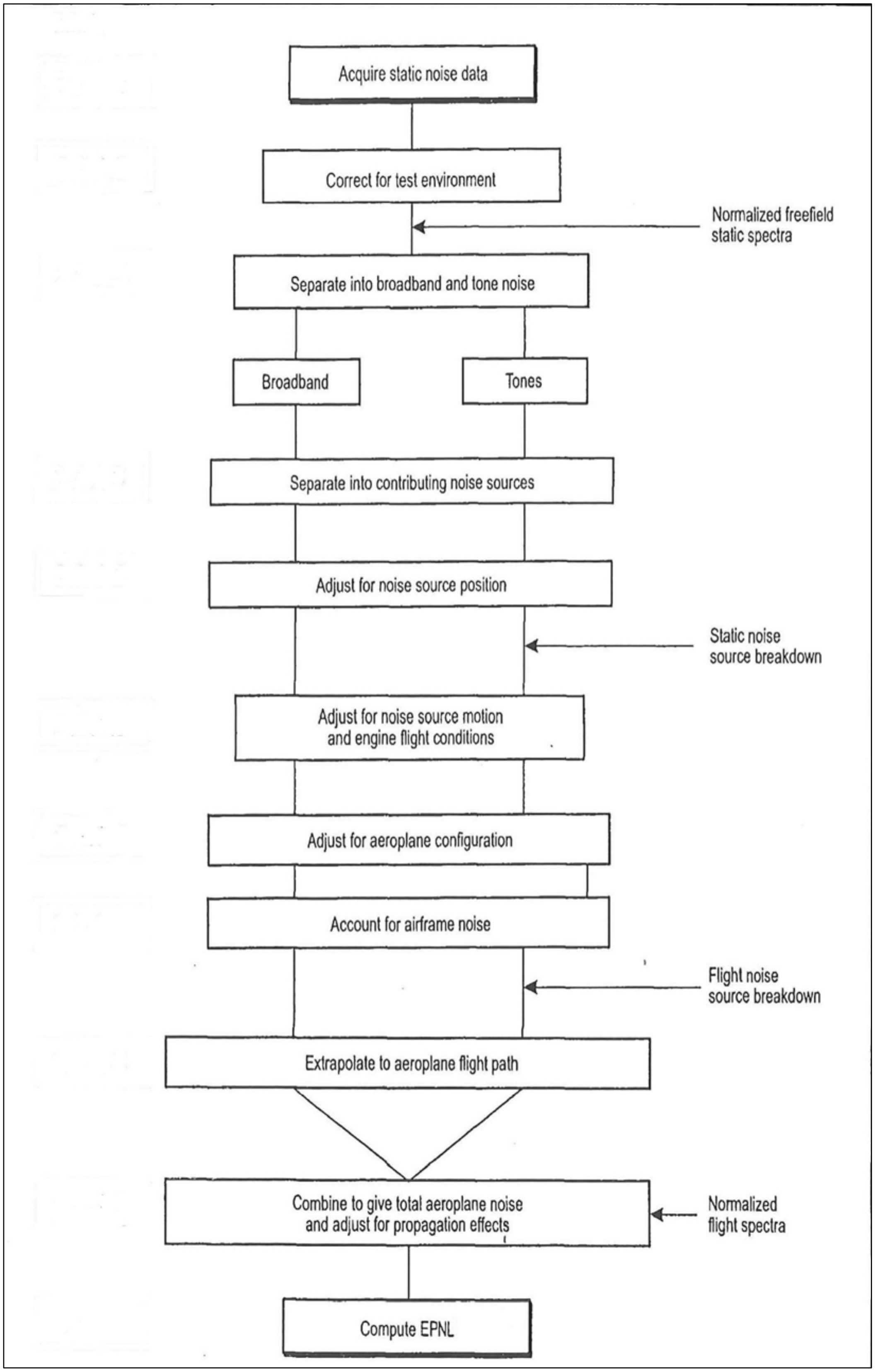


Figure 3-25 Generalized projection of static engine data to aeroplane flight conditions (Refer to 3.2.1.3)

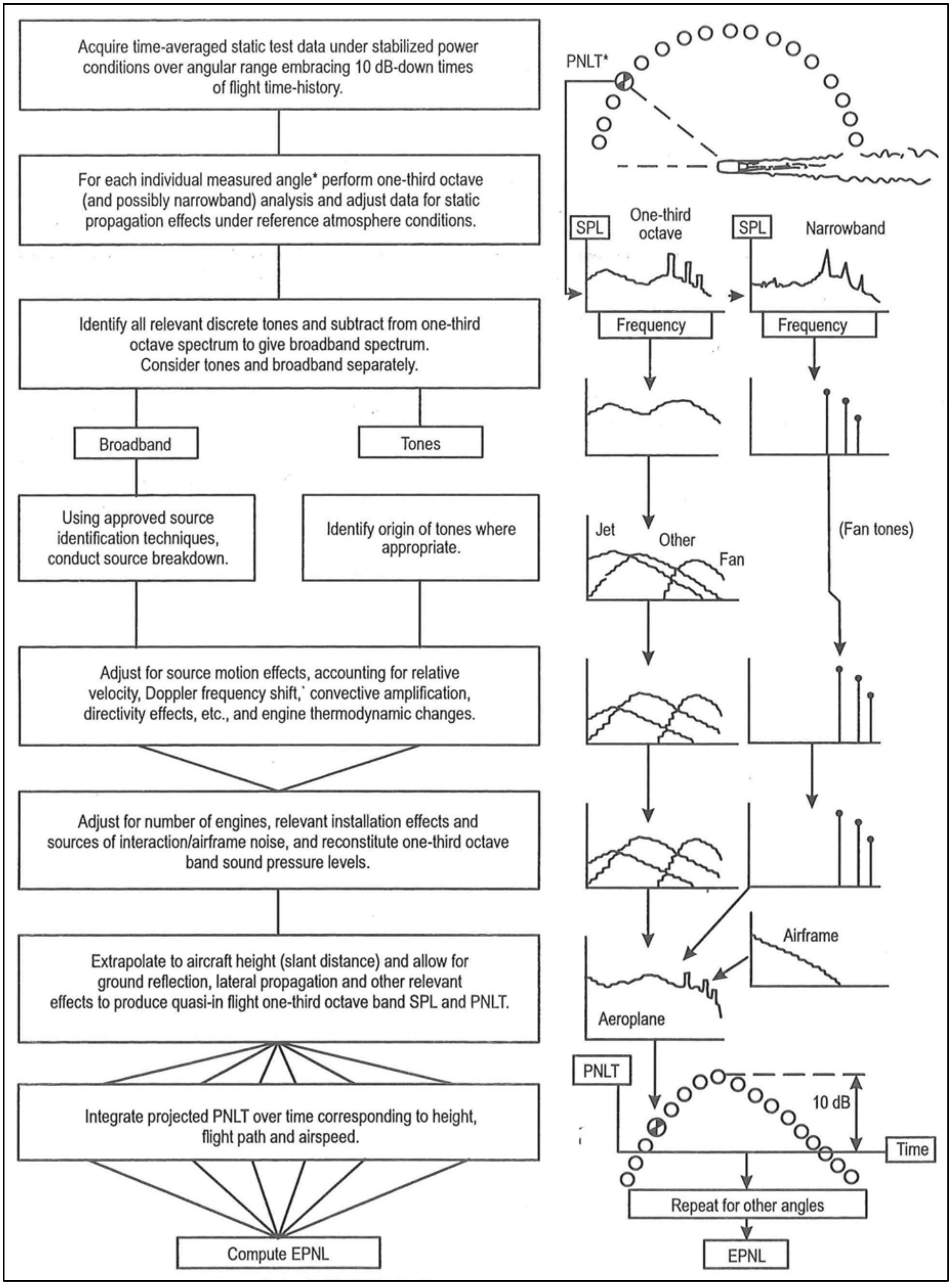


Figure 3-26 Example procedure for projection of static engine data to aeroplane flight conditions

There are several engine installation effects which can modify the generated noise levels but which cannot be derived from static tests. Additional noise sources such as jet/flap or jet/wind interaction effects may be introduced on a derived version of the aeroplane which are not present on the "flight datum" aeroplane. Far-field noise directivity patterns (i.e. field shapes) may be modified by wing/nacelle or jet-by-jet shielding, tailplane and fuselage scattering or airframe reflection effects. However general methods to adjust for these effects are not yet available. It is therefore important that before the following procedures are approved for the derived version of the aeroplane the geometry of the airframe and engines in the vicinity of the engines be shown to be essentially identical to that of the "flight datum" aeroplanes so that the radiated noise is essentially unaffected.

3.2.1.3.4.2 _Normalization to reference conditions_

The analysed one-third octave band sound pressure level static test data should be normalized to free-field reference atmospheric conditions specified in 3.6.1.5 of Chapter 3 of the Annex. This adjustment can only be applied with knowledge of the total spectra being the summation of all the noise source spectra computed as described in the following paragraphs.

The required adjustments include:

a) Sound Atenuation Due to Atmospheric Absorption

Adjustments to account for the acoustical reference-day sound attenuation are defined in Reference 11. In the event that minor differences in coefficient values are found in Reference 11 between equations, tables or graphs, the equations should be used. The sound attenuation coefficients should be computed over the actual distance from the effective centre of each noise source to each microphone, as described in 3.2.1.3.4.5.

b) *Ground reflection*

Examples of methods for obtaining free-field sound pressure levels are described in References 12 and 13. Spatial distribution of noise sources do not have a first order influence on ground reflection effects and hence may be disregarded. It is also noted that measurements of far-field sound pressure levels with ground-plane microphones may be used to avoid the large spectral irregularities caused by interference effects at frequencies less than 1 kHz.

3.2.1.3.4.3 _Separation into broadband and tone noise_

The purpose of procedures described in this section is to identify all significant tones in the spectra, firstly to ensure that tones are not included in the subsequent estimation of broadband noise, and secondly to enable the Doppler-shifted tones in-flight to be allocated to the correct one-third octave band at appropriate times during a simulated aeroplane flyover.

Broadband noise should be derived by extracting all significant tones from the measured spectra. One concept for the identification of discrete tones is the one used in Appendix 2 of the Annex for tone correction purposes (i.e. considering the slopes between adjacent one-third octave band levels). Care must be taken to avoid regarding tones as "non protrusive" when the surrounding broadband sound pressure level is likely to be lower when adjusted from static to flight conditions, or when classifying a closely grouped pair or series of tones as broadband noise. One technique for resolving such problems is the use of narrow-band analysis with a bandwidth of less than 50 Hz.

Narrow-band analysis can also be used to check the validity of other tone identification procedures in establishing the spectral character at critical locations in the sound field (e.g. around the position of peak PNLT) or where predominant turbo-machinery tones exist.

3.2.1.3.4.4 _Separation into contributing noise sources_

The number of noise sources which require identification will to some extent depend on the engine being tested and the nature of the change to the engine or nacelle. The separation of broadband noise into the combination of noise generated by external jet mixing and by internal noise sources is the minimum and sometimes adequate requirement. A more sophisticated analysis may be necessary depending upon the significance of the contribution from other individual sources, which could involve identifying broadband noise from fan, compressor, combustor and turbine. Furthermore, for fan and compressor noise, the split of both the broadband and the tone noise between that radiating from the engine intake and that from the engine exhaust nozzle(s) could be a further refinement.

To meet the minimum requirement, the separation of sources of broadband noise into those due to external jet mixing and those generated internally can be carried out by:

a) estimating the jet noise by one or more of the methods identified below; and

b) adjusting the level of the predicted spectrum at each angle to fit the measured low frequency part of the broadband spectrum at which jet noise can be expected to be dominant.

There are three methods which have been used to obtain predicted jet noise spectra shapes:

a) For single-stream engines with circular nozzles, the procedure detailed in Reference 14 may be used. The engine geometry however may possess features which can render this method inapplicable. Sample procedures for coaxial flow engines are provided in Reference 15;

b) Analytical procedures based on correlating full-scale engine data with model nozzle characteristics may be used. Model data have been used to supplement full-scale engine data, particularly at low power settings, because of the uncertainty in defining the level of jet noise at the higher frequencies where noise from other engine sources may make a significant contribution to the broadband noise; and

c) Special noise source location techniques are available which, when used during full-scale engine tests, can identify the positions and levels of separate engine noise sources.

3.2.1.3.4.5 Noise source position effects

Static engine noise measurements are often made at distances at which engine noise sources cannot be truly treated as radiating from a single acoustic centre. This may not give rise to difficulties in the extrapolation to determine the noise increments from static data to flight conditions because noise increments in EPNL are not particularly sensitive to the assumption made regarding the spatial distribution of noise sources.

However, in some circumstances, for example where changes are made to exhaust structures and where the sources of external jet-mixing noise are of overriding significance, it may be appropriate to identify noise source positions more accurately. The jet noise can be considered as a noise source distributed downstream of the engine exhaust plane. Internal sources of broadband engine noise may be considered as radiating from the intake and the exhaust.

There are three principal effects to be accounted for as a consequence of the position of the noise source differing from the “nominal” position assumed for the “source” of engine noise:

a) *Spherical divergence*

The distance of the source from the microphone differs from the nominal distance, in which case an inverse square law adjustment needs to be applied;

b) *Directivity*

The angle subtended by the line from the source to the microphone and the source to the engine centre line differs from the nominal angle, in which case a linear interpolation should be made to obtain data for the proper angle; and

c) *Sound attenuation due to atmospheric absorption*

The difference between the true and the nominal distance between the source and the microphone alters the allowance made for sound attenuation.

Source position can be identified either from noise source location measurements (made either at full or model scale) or from a generalized database.

Note.- No published standard on coaxial jet noise source distribution is currently available. An approximate distribution for a single jet is given by the following equation (see References 16 and 17):

$$x/D=(0.0575S + 0.0215S^{-2})^{-½}$$

where:

- S is the Strouhal number fD/V_j;
- x is the distance downstream from the nozzle exit;
- D is the nozzle diameter based on total nozzle exit area;
- V_j is the average jet velocity for complete isentropic expansion to ambient pressure from average nozzle-exit pressure and temperature; and
- f is the one-third octave band centre frequency.

3.2.1.3.4.6 Engine flight conditions

Some thermodynamic conditions within an engine tested statically differ from those that exist in flight and this difference should be taken into account. Noise source strengths may be changed accordingly. Therefore, the values for key correlating parameters for component noise source generation should be based on the flight condition, and the static database should be entered at the appropriate correlating parameter value. Turbo-machinery noise levels should be based on the in-flight corrected rotor speeds $N_1/\sqrt{\theta_{t_2}}$. Jet noise levels should be based on the relative jet velocities that exist at the flight condition.

The variation of source noise levels with key correlating parameters can be determined from the static database which includes a number of different thermodynamic operating conditions.

3.2.1.3.4.7 Noise source motion effects

The effects of motion on jet noise differ from speed effects on other noise sources, and hence are considered separately during static-to-flight projection.

a) *For external jet noise*

Account should be taken of the frequency-dependent jet relative velocity effects and the convective amplification effects. Broadly speaking, two sources of information may be used to develop an approved method for defining the effect of flight on external jet noise:

- For single-stream engines with circular exhaust geometries, Reference 14 provides guidance. Additional supporting evidence however may be needed to show when jet noise is the major contributor to the noise from an engine with a more complex nozzle assembly ; and
- Full-scale flight data on a similar exhaust geometry can provide additional evidence. In general however, because of the difficulty of defining high frequency effects in the presence of internally-generated engine noise, it may be necessary to provide additional supporting information to determine the variation of EPNL with changes of jet noise spectra at high frequencies.

b) *For noise sources other than jet noise*

In addition to the Doppler frequency effect on the non-jet noise observed on the ground from an aeroplane flyover, the noise generated by the engine's internal components and the airframe can be influenced by source amplitude modification and directivity changes:

– *Doppler effect.* Frequency shifting that results from motion of the source (i.e. aeroplane) relative to amicrophone is accounted for by the following equation:

$$f_{flight} = \frac{f_{static}}{(1 - M \cos \lambda)}$$

where:

– *f flight = flight frequency;*

– f_{static} = static frequency;

– M = Mach number of aeroplane; and

– λ = angle between the flight path in the direction of flight and a straight line connecting the aeroplane and the microphone at the time of sound emission.

It should be noted for those one-third octave band sound pressure levels dominated by a turbo-machinery tone, the Doppler shift may move the tone and its harmonics into an adjacent band.

– *Source amplitude modification and directivity changes.* One-third octave band sound pressure level adjustments to airframe-generated noise that results from speed changes between the datum and derivative versions provided below.

For noise generated internally within the engine (e.g. fan noise), there is no consensus of opinion on the mechanisms involved or on a unique adjustment method that accounts for the detailed source modification and sound propagation effects. If an adjustment is used, the same technique must be applied to both the flight datum and derivative configuration when establishing noise changes. In such instances the adjustment for the one-third octave band sound pressure level changes that result from the motion of the source (i.e. aeroplane) relative to the microphone may be accounted for by using the following equation:

$$SPL_{flight} = SPL_{static} - K \log(1 - M \cos \lambda)$$

where:

– SPL_{flight} = flight sound pressure level;

– SPL_{static} = static sound pressure level; and

– M and λ are defined above and K is a constant.

Theoretically, K has a value of 40 for a point noise source but a more appropriate value may be obtained by comparing static and flight data for the "flight datum" aeroplane.

3.2.1.3.4.8 Aeroplane configuration effects

The contribution from more than one engine on an aeroplane is normally taken into account by adding *10 log N*, where N is the number of engines, to each component noise source. It might be necessary however to compute the noise from engines widely spaced on large aeroplanes, particularly in the approach case, if they include both underwing and fuselage mountings. The noise from the intakes of engines mounted above the fuselage is known to be shielded.

If engine installation effects change between the "flight datum" aeroplane and a derived version, account should be taken of the change on one-third octave band sound pressure levels which should be estimated according to the best available evidence.

3.2.1.3.4.9 *Airframe noise*

To account for the contribution of airframe noise, measured flight datum airframe noise on its own or combined with an approved airframe noise analytical model may be used to develop an airframe noise database. The airframe-generated noise, which can be treated as a point source for adjustment purposes, is normalized to the same conditions as those of the other (i.e. engine) sources, with due account given for the effects of spherical divergence, atmospheric absorption and airspeed as described in Appendix 2 of the Annex.

Airframe noise for a specific configuration varies with airspeed (see Reference 18) as follows:

$$\Delta SPL_{airframe} = 50\log(V_{REF}/V_{TEST})$$

where:

- V_{REF} is the approved reference airspeed for the "*flight datum*" aeroplane; and
- V_{TEST} is model or measured airspeed.

The above equation is also valid for adjustments to EPNL where an empirically derived coefficient replaces the coefficient 50 since that number may be somewhat configuration-dependent. However, the approval of the certification authority is required for values other than 50.

3.2.1.3.4.10 *Aeroplane flight path considerations*

When computing the one-third octave band sound pressure levels corresponding to the slant distance of the aeroplane in flight from the noise measuring point, the principal effects are spherical divergence (inverse square law) adjustments from the nominal static distance and sound attenuation due to atmospheric absorption (as described in Appendix 2 of the Annex). Furthermore, account should be taken of the difference between the static engine axis and that axis in flight relative to the reference noise measuring points. The adjustments should be applied to the component noise source levels that have been separately identified.

3.2.1.3.4.11 *Total noise spectra*

Both the engine tonal and broadband noise source components in flight, together with the airframe noise and any installation effects, are summed up on a mean-square pressure basis to construct the spectra of total aeroplane noise levels.

During the merging of broadband and tonal components, consideration should be given to appropriate band sharing of discrete frequency tones.

The effects of ground reflections must be included in the estimate of free-field sound pressure levels in order to simulate the sound pressure levels that would be measured by a microphone at a height of 1.2 m (4 ft) above a natural terrain. Information in Reference 12 or 13, may be used to apply adjustments to the free-field spectra to allow for flight measurements being made at 1.2 m (4 ft). Alternatively, the ground reflection adjustment can be derived from other approved analytical or empirically derived models. Note that the Doppler adjustment for a static source at frequency (f_{static}) applies to a moving (i.e. aeroplane) source at a frequency (f_{flight}) where $f_{\text{flight}} = f_{\text{static}}/(1 - M\cos\lambda)$ using the same terminology as described above for Doppler Effect. This process is repeated for each measurement angle and for each engine power setting.

With regard to lateral attenuation, the information in Reference 19, applicable to the computation of lateral noise may be applied.

3.2.1.3.4.12 *EPNL computations*

For EPNL calculations, a time is associated with each extrapolated spectrum along the flight path. Note that the time is associated with each measurement location with respect to the engine/aeroplane reference point and the aeroplane's true airspeed along the reference flight path assuming zero wind. For each engine power setting and minimum distance an EPNL is computed from the projected time history using the methods described in Appendix 2 of the Annex.

3.2.1.3.4.13 *Changes to noise levels*

An NPD plot can be constructed from the projected static data for both the original (i.e. flight datum) and the changed configurations of the engine or nacelle tested. Comparisons of the noise versus engine thrust (power) relationships for the two configurations at the same appropriate minimum distance will determine whether or not the changed configuration resulted in a change to the noise level from an engine noise source. If there is a change in the level of source noise, a new in-flight aeroplane NPD plot can be developed by adjusting the measured original NPD plot by the amount of change indicated by the comparison of the static-projected NPD plots for the original and changed versions within the limitations specified in 3.2.1.3.2 for EPNL.

The noise certification levels for the derived version of an aeroplane may be determined from NPD plots at the relevant reference engine power and distance, with an additional adjustment of [$10 \log V_{nom}/V_r$] for the velocity of the aeroplane at the certification reference condition relative to the nominal velocity (V_{nom}) used in developing the NPD plots.

3.2.2 Propeller-driven aeroplanes over 8618 kg

The procedures described in this Chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass exceeding 8618 kg, as provided in Chapters 3 and Chapter 5 of the Annex.

3.2.2.1 *Flight test procedures*

3.2.2.1.1 Flight path intercept procedures

Flight path intercept procedures, as described in 3.2.1.1.1, have been used to meet the demonstration requirements of noise certification in lieu of full take-offs and/or landings.

3.2.2.1.2 Generalized flight test procedures

Generalized flight test procedures, other than normal noise demonstration take-offs and approaches, have been used to meet two equivalency objectives:

a) *NPD plots*

Noise data is acquired over a range of engine power settings at one or more heights. This information permits the development of generalized noise characteristics necessary for the certification of a “family” of similar aeroplanes. The procedures used are similar to those described in 3.2.1.1.2, with the exception that the noise-power-distance (NPD) plots employ engine noise performance parameters (μ) of propeller helical tip Mach number (M_H) and shaft horsepower (SHP/δ_{amb}) (see Figure 3-27), where δ_{amb} is defined in 3.2.1.1.2.1.

In order to ensure that propeller inflow angles are similar throughout the development of the noise-sensitivity data as the aeroplane mass changes, the airspeed of the aeroplane used in the flight tests for developing the lateral and flyover data shall be V_2 + *19 km/h* (V_2 + *10 kt*) to within ± 6 km/h (± 3 kt), as appropriate for the mass of the aeroplane during the test.

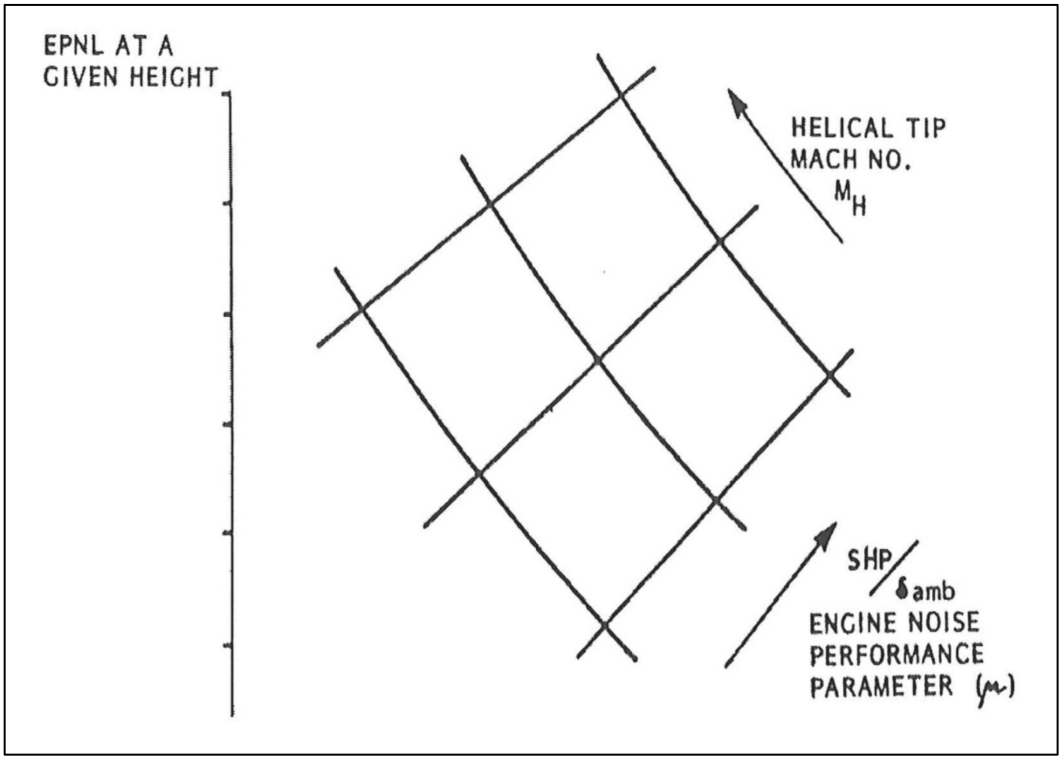


Figure 3-27 Form of noise-power-distance (NPD) plot for heavy propeller-driven aeroplanes

For the development of the NPD data for the approach case, the speed and approach angle constraints imposed in 3.6.3, 3.7.5, 4.5, 4.6, 5.6.3b and 5.7.5 of Chapters 3, 4 and 5 respectively of the Annex cannot be satisfied over the typical range of power needed. For the approach case, a steady speed of V_{REF} + *19 km/h* (V_{REF} + *10 kt*) should be maintained to within ± 6 km/h (± 3 kt) and the flyover height over the microphone should be 122 ± 30 m (400 ± 100 ft). Within these constraints, the test approach angle at the test power should be that which results from the test aeroplane conditions (i.e. mass, configuration, speed and power).

b) *Noise level changes*

Comparisons are made of flyover noise test data for different developments of an aeroplane type (e.g. a change in propeller type). Such changes are used to establish certification noise levels of a newly derived version as described in 3.2.1.1.2.

3.2.2.1.3 Determination of the lateral noise certification level

For propeller-driven aeroplanes, Amendment 5 of the Annex introduced into Chapter 3 a full-power measurement point under the flight path as a replacement for the lateral measurement point. However, for those aeroplanes for which the 2-microphone lateral measurement method was applicable, this section describes appropriate equivalent procedures.

Determination of the lateral noise certification level employing an alternative procedure using two microphone stations located symmetrically on either side of the take-off flight path similar to that as described in 3.2.1.1.3 has been approved. However, when this procedure is used, matching data from both lateral microphones for each fly-by must be used for the lateral noise determination. Cases where data from only one microphone is available for a given fly-by must be omitted from the determination. The following paragraphs describe the procedures for propeller-driven heavy aeroplanes:

a) The lateral Effective Perceived Noise Level (EPNL) from propeller-driven aeroplanes, when plotted against height opposite the measuring sites, can exhibit distinct asymmetry. The maximum EPNL on one side of the aeroplane is often at a different height and noise level from that measured on the other side;

b) In order to determine the average maximum lateral EPNL (i.e. the certification sideline noise level) it is therefore necessary to undertake a number of flights over a range of heights to define the noise versus height characteristics for each side of the aeroplane. A typical height range would cover between 30 m (100 ft) and 550 m (1800 ft) above a track at right angles to and midway along the line joining the two microphone stations. The intersection of the track with this line is defined as the reference point;

c) Since experience has shown the maximum lateral noise level may often be near the lower end of this range a minimum of six good sets of data, measured simultaneously from both sides of the flight track, should be obtained for a range of aeroplane heights as low as possible. In this case take-offs may be necessary. However care should be taken to ensure that the airspeed is stabilized to at least V2 + 19 km/h (V2 + 10 kt) over the 10 dB-down period;

d) The aeroplane climbs over the reference point using take-off power, speeds and configuration as described in 3.6.2c and 3.6.2d of Chapter 3 or 5.6.2c and 5.6.2d of Chapter 5 of the Annex.

e) The lateral certification noise level is obtained by finding the peak of the curve of noise level (EPNL) corrected to reference-day atmospheric absorption values and plotted against aeroplane height above the reference point (see Figure 3-28). This curve is described as a least squares curve fit through the data points defined by the median values of each pair of matched data measured on each side of the track (i.e. the average of the two microphone measurements for a given aeroplane height); and

f) To ensure that the requirements of 5.4.2 of Appendix 2 of the Annex are met, the 90 per cent confidence limits should be determined in accordance with 2.5.

3.2.2.1.4 Measurements at non-reference points

In some instances, test measurement points may differ from the reference measurement points as specified in Chapters 3 and 5 of the Annex. Under these circumstances an applicant may request approval of data that have been adjusted from actual measurements to the reference conditions for reasons described in 3.2.1.1.5.

Noise measurements collected closer to the test aeroplane than at the certification reference points are particularly useful for adjusting propeller noise data as they are dominated by low frequency noise. The spectra roll off rapidly at higher frequencies and are often lost in the background noise at frequencies above 5 000 Hz. Section 2.6.3 describes a procedure for background noise adjustment.

Non-reference measurement points may be used provided that measured data are adjusted to reference conditions in accordance with the requirements of section 9 of Appendix 2 of the Annex, and that the magnitude of the adjustments does not exceed the limits cited in 3.7.6 of Chapter 3 and 5.7.6 of Chapter 5 of the Annex.

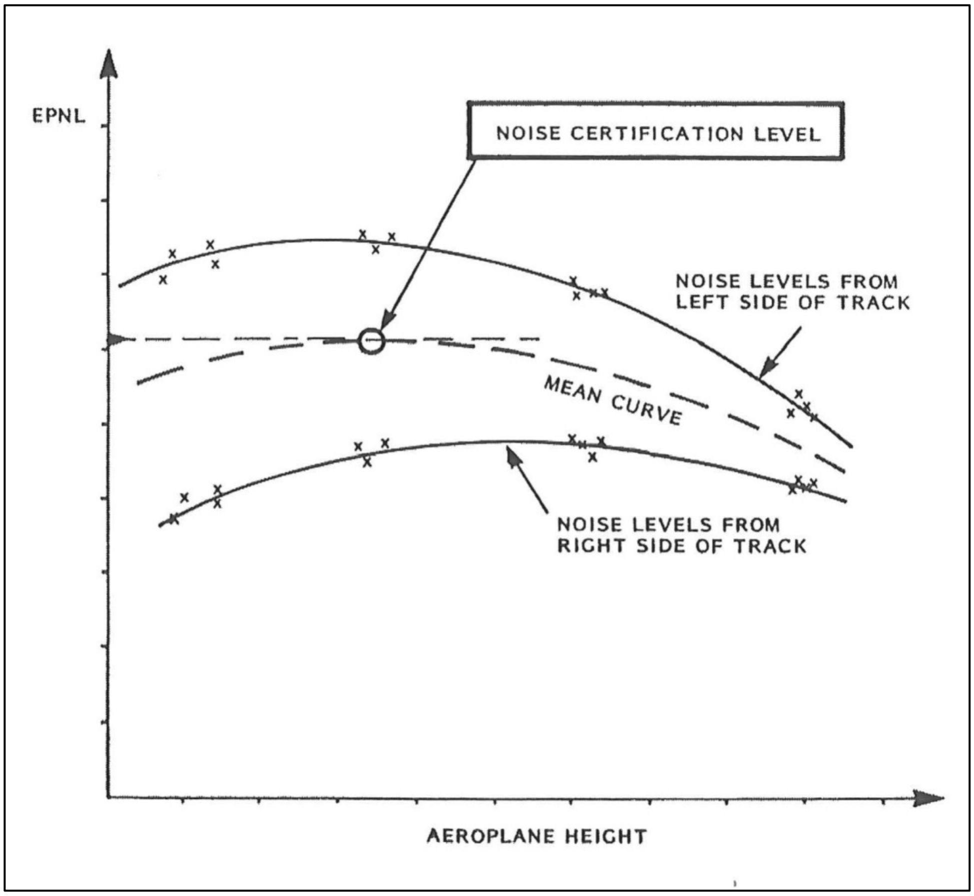


Figure 3-28 Typical lateral noise data plot for heavy propeller-driven aeroplanes

3.2.2.2 ***Analytical procedures***

Equivalent analytical procedures rely upon the available noise and performance data of an aeroplane type. The generalized relationships between noise levels, propeller helical tip Mach number, and shaft horsepower, as well as the adjustment procedures for speed and height changes in accordance with the methods of Appendix 2 of the Annex are combined with certificated aeroplane performance data in order to determine noise level changes resulting from type design changes. The noise level changes are then added to or subtracted from the noise certification levels that are demonstrated by flight test measurements for the "flight datum" aeroplane.

Certifications using analytical procedures have been approved for type design changes that result in predictable noise level differences. The type design changes include the following:

a) an increase or decrease in maximum take-off and/or landing mass of the aeroplane from the originally certificated mass;

b) power increase or decrease for engines that are acoustically similar and fitted with propellers of the same type;

c) aeroplane engine and nacelle configuration changes, usually minor in nature, including derivative aeroplane models with changes in fuselage length and flap configuration. Care is however needed to ensure that the existing noise sources are not modified by these changes (e.g. by changing the flow field into the propellers); and

d) minor airframe design changes that could indirectly affect noise levels because of an impact on aeroplane performance (e.g. increased drag). Changes in aeroplane performance characteristics derived from aerodynamic analysis or testing have been used to demonstrate how these changes can affect the aeroplane flight path and consequently the demonstrated noise levels of the aeroplane.

3.2.2.3 ***Ground static testing procedures***

3.2.2.3.1 General

Unlike the case of a turbojet or turbofan powerplant, static tests involving changes to the propeller are not applicable for determining noise level changes in the development of a propeller-driven aeroplane/powerplant family because of changes in the aero-acoustic operating conditions of the propeller when run statically compared with conditions existing during flight. The propeller noise levels measured during a static test can include significant contributions from noise source components that are not normally important in flight. However, limited static tests on engines with propellers, which are used as engine loading devices, can be utilized to determine small noise changes, as described below.

3.2.2.3.2 Guidance on the test site characteristics

Guidance on the test site characteristics data acquisition and analysis systems, microphone locations, acoustical calibration and measurement procedures for static testing, is provided in Reference 10 and is equally valid in these respects for propeller powerplants (see 3.2.1.3.3).

3.2.2.3.3 Static tests of the gas generator

Static tests of the gas generator can be used to identify noise changes resulting from changes to the design of the gas generators or to the internal structure of the engine in the frequency ranges:

a) where there is a contribution to the aeroplane EPNL; or

b) where that part of the spectrum is clearly dominated by the gas generator; or

c) where ancillary equipment under circumstances where the propeller and its aerodynamic performance remains unchanged.

Such circumstances where the propeller and its aerodynamic performance remain unchanged include, for example, changes to the compressor, turbine or combustor of the powerplant. The effect of such changes should be conducted under the same test, measurement, data reduction and extrapolation procedures as described in 3.2.1.3 for turbojet and turbofan engines. The noise emanating from any propeller or other power extraction device used in static tests should be eliminated or removed analytically. For the purposes of aeroplane EPNL calculation, the measured "flight datum" aeroplane propeller contributions should be included in the computation process.

3.2.3 Helicopters

The objective of a noise certification test is to acquire data for establishing an accurate and reliable definition of a helicopter's noise characteristics (see 8.7 of Chapter 8 of the Annex). The Annex establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

3.2.3.1 *Flight test procedures*

3.2.3.1.1 Helicopter test speed

There are two requirements for helicopter test speeds. Firstly, the airspeed during the 10 dB-down period should be close to the reference speed (i.e. within ± 9 km/h (± 5 kt), see 8.7.6 of Chapter 8 of the Annex) in order to minimize speed adjustments for the three certification conditions of take-off, overflight and approach.

The second speed requirement applies to the overflight case (see 8.7.7 of Chapter 8 of the Annex). The number of level overflights made with a head wind component shall be equal to the number of overflights made with a tailwind component. The objective is to minimize the effect of wind on the measured overflight noise levels. If, however, the absolute wind speed component in the direction of flight, as measured at a height of 10 m (33 ft) above ground, is less than ± 9 km/h (± 5 kt), then the effect of wind direction can be considered to be negligible. In this case, the measured overflight can be considered to be either a headwind or tailwind test run.

The applicant may find that although there are at least three valid overflights with a headwind component and three valid overflights with a tailwind component, there are more valid overflights with one wind component than with another. In this case, the applicant will need to discuss with the certificating authority which overflights are to be used in the determination of the final EPNL value for overflight. In many cases, preference may be given to using level overflights performed in pairs in order that the meteorological conditions are as similar as possible for the two overflights in each pair. Hence, there is merit in considering conducting overflights in pairs for all wind speed conditions. Each pair should consist of two overflights performed one after the other in opposite directions along the reference flight track.

The measurement of ground speed may be obtained by timing the helicopter as it passes over two points at a known distance apart on the helicopter track during the overflight noise measurements. These two points should straddle the noise measurement microphone array.

3.2.3.1.2 Atmospheric test conditions

The temperature, relative humidity and wind velocity limitations are contained in 2.2.2.2 of Appendix 2 of the Annex. The parameters are measured at 10 m (33 ft) within 2000 m (6562 ft) of the flight track noise measurement point at a location subject to approval by the certificating authority. For adjustment purposes the measured values of these parameters are assumed to be representative of the air mass between the helicopter and the microphones. No calculation procedures based on the division of the atmosphere into layers are required, but such a method of analysis could be accepted by the certificating authority.

3.2.3.1.3 Temperature and Relative Humidity Measurements

Temperature and relative humidity measurements, as defined in 2.2.2.5 of Appendix 2 of the Annex have to be made at a height of 10 m (33 ft) above the ground. The measured values are used in the adjustment of the measured one-third octave band sound pressure levels for the effects of atmospheric absorption to account for the difference in the sound attenuation coefficients in the test and reference atmospheric conditions as given in 8.3.1 of Appendix 2 of the Annex. The distances QK and Q_rK_r in the equations of 8.3.1 refer to the distances between positions on the measured and reference flight paths corresponding to the PNLTM position and the noise measurement point.

As a consequence the procedure assumes that the difference between the temperature and relative humidity at 10 m (33 ft) and the PNLTM position is zero or small and that the atmosphere can be represented by the values measured at 10 m (33 ft) above the ground in the vicinity of the noise measurement point (i.e. within 2000 m (6562 ft) of the flight track noise measurement point). Data obtained from European and U.S. certification tests over a number of years and records provided by the U.K. Meteorological Office, have confirmed that this assumption is valid over a wide range of meteorological conditions.

Noise certification measurements may be made under test conditions where significant changes in temperature and/or relative humidity with height are expected. Of particular concern are conditions when a significant drop in humidity with altitude is expected. Such special conditions might be encountered in desert areas shortly after sunrise where the temperature near the ground is lower and the relative humidity considerable higher, than at the height associated with the PNLTM point. Measurements made under such conditions should be adjusted by using the average of the temperature and relative humidity measured at 10 m (33 ft) above the ground and at the height associated with the PNLTM point in order to eliminate errors associated with the use of data measured at 10 m (33 ft) only (see also 3.2.3.1.5).

Section 2.2.2.2 of Appendix 2 of the Annex limits testing to conditions where the sound attenuation rate in the 8 kHz one-third octave band is not more than 12 dB/100 m. If, however, the dew point and dry bulb temperature are measured with a device which is accurate to within ± 0.5°C, it has been found acceptable by certificating authorities to permit testing in conditions where the 8 kHz sound attenuation rate is not more than 14 dB/100 m.

3.2.3.1.4 <u>Modifications or upgrades involving aerodynamic drag changes</u>

The use of drag devices, such as drag plates mounted beneath or on the sides of the "flight datum" helicopter, has proven to be effective in the noise certification of modifications or upgrades involving aerodynamic drag changes. External modifications of this type are made by manufacturers and aircraft "modifiers". Considerable cost savings are realised by not having to perform noise testing of numerous individual modifications to the same model series. Based on these findings it is considered acceptable to use the following as an equivalent procedure:

a) For helicopters to be certificated under Chapter 8 of the Annex a drag device is used that produces the aerodynamic drag calculated for the highest drag modification or combination of modifications;

b) With the drag-producing device installed an overflight test and, if considered appropriate by the certificating authority, take-off and/or approach tests are performed by using the appropriate noise certification reference and test procedures;

c) A relationship of noise level versus change in aerodynamic drag or airspeed is developed by using noise data (adjusted as specified in Appendix 2 of the Annex) of the "flight datum" helicopter and of the "high drag" configuration;

d) The actual airspeed of the modification to be certificated is determined from performance flight testing of the baseline helicopter with the modification installed; and

e) Using the measured airspeed of the modification, certification noise levels are determined by interpolation of the relationship developed in item c.

Note.- Modifications or upgrades involving aerodynamic drag changes that do not require noise certification are described in 1.2.1.

3.2.3.1.5 <u>Anomalous Test Conditions</u>

Section 2.2.2.2 of Appendix 2 of the Annex requires that the tests be conducted under conditions where no anomalous meteorological conditions exist. The presence of anomalous atmospheric conditions can be determined to a sufficient level of certainty by monitoring the outside air temperature (OAT) with the use of the aircraft instruments. Anomalous conditions which could impact the measured levels can be expected to exist when the OAT at 150 m (492 ft) is higher by 2°C (3.6°F) or more than the temperature measured at 10 m (33 ft) above ground level. This check can be made in level flight at a height of 150 m (492 ft) within 30 minutes of each noise measurement.

Since the actual heights associated with the PNLTM points will not be known until the analysis is made, measurements of temperature and relative humidity can be made at a number of heights and the actual value determined from a chart of temperature and relative humidity versus height. Alternatively, since the influence of height is small, measurements at a fixed height in the order of 120 m (394 ft) and 150 m (492 ft) can be used depending on the flight condition and agreed with the certificating authority prior to the tests being conducted.

If tests are adjusted by using the “average” of the temperature and relative humidity measured at 10 m (33 ft) and the height associated with the PNLTM point (as described in the third paragraph of 3.2.3.1.3) then the provisions of the first paragraph of this section do not apply. The reason is that the impact of any anomalous meteorological conditions are taken into account by using the average of the temperature and relative humidity at 10 m (33 ft) and the height associated with the PNLTM point.

3.2.3.1.6 Helicopter test rotor speed

Operational rotor speed modes (e.g. CAT A) can form part of the Rotorcraft Flight Manual normal procedures and are used under specific operational circumstances. They typically involve airspeed ranges below those of the certification reference procedures. However, in some cases, such as a high pilot workload in the final approach phase combined with IFR conditions, their use has been permitted at higher airspeeds which includes the reference speed for noise certification. Hence, the maximum normal operating rotor speed corresponding to the reference flight condition should take into account any relevant operational rotor speed mode. The decision on how and which operational rotor speed modes are to be applied for noise certification is normally coordinated with the flight test experts of the certification authority and is dealt with on a case by case basis.

3.2.3.1.7 Helicopter test mass

The mass of the helicopter during the noise certification demonstration (see 8.7.11 of Chapter 8 of the Annex) must lie within the range of 90 per cent to 105 per cent of the maximum take-off mass for the take-off and overflight demonstrations and between 90 per cent to 105 per cent of the maximum landing mass for the approach demonstration. For noise certification purposes the effect of change of mass is to change the test-day flight path for take-off, and adjustments to the reference flight path should be made for spherical spreading and atmospheric attenuation as described in section 8 of Appendix 2 of the Annex.

In some cases, such as when the test aircraft mass is restricted to a value somewhat less than the anticipated final certification mass, the applicant may, subject to the approval of the certificating authority, apply specific adjustments for mass variations. The applicant may be approved to use a 10-log relationship adjustment or otherwise determine, by flight test, the variation of EPNL with mass. In such a case, the masses tested should include the maximum allowable test mass.

Note.- A similar adjustment procedure may be acceptable when the certificated mass is increased by a small amount subsequent to the flight tests

3.2.3.1.8 Helicopter approach

Section 8.7.10 of Chapter 8 of the Annex constrains the approach demonstration to within ± 0.5° of the reference approach angle of 6°. Adjustments of the noise data to the reference approach angle are required to account for spherical spreading effects and atmospheric attenuation as described in section 8 of Appendix 2of the Annex.

3.2.3.2 *Analytical Procedures*

3.2.3.2.1 Helicopter test window for zero adjustment for atmospheric attenuation

There is currently a "test window" contained in 2.2.2.2 of Appendix 2 of the Annex which needs to be met before test results are acceptable to certificating authorities. In addition if the test conditions fall within a “zero attenuation adjustment window” (see Figure 3-29), defined as the area enclosed by (2°C, 95 per cent RH), (30°C, 95 per cent RH), (30°C, 35 per cent RH), (15°C, 50 per cent RH) and (2°C, 90 per cent RH), then the sound attenuation adjustment of the test data may be assumed to be zero.

Accordingly the terms:

$0.01\ [\alpha(i) - \alpha(i)_0]\ QK$ *,and*

$0.01\,\alpha(i)_0\,(QK - Q_rK_r)$,

from the equation for $SPL(i)_r$ in 8.3.1 of Appendix 2 of the Annex become zero and the equation for $SPL(i)_r$ becomes:

$$SPL(i)_r = SPL(i) + 20\log(QK/Q_rK_r)\ .$$

Furthermore, in this equation QK and QrKr may be replaced by the test and reference distances to the helicopter when the helicopter is over the centre noise measuring point provided that all the measured points for a particular flight condition are:

a) flown in test conditions within the “zero attenuation adjustment window” defined in Figure 3-29; and

b) for overflight the height is 150 ± 9 m (492 ± 30 ft);

c) for approach the height over the microphone is 120 ± 10 m (492 ± 33 ft); and

d) for take-off the distance adjustment given in 8.7.4a of Chapter 8 of the Annex is not greater than 2 EPNdB.

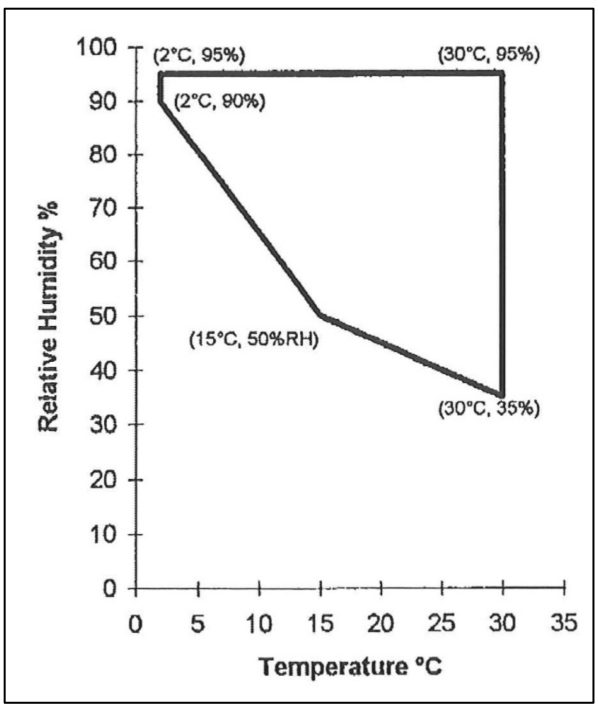


Figure 3-29 Chapter 8 zero attenuation adjustment window

The total effect of both simplifications cited above is that the equation of 8.3.1 of Appendix 2 of the Annex becomes:

$$SPL(i)_r = SPL(i) + 20\log(HK/H_rK_r)\,,$$

and the duration adjustment term specified in 8.4.2 of Appendix 2 of the Annex becomes:

$$\Delta_2 = -7.5\log(HK/H_rK_r) + 10\log(V/V_r)\,,$$

where HK is the measured distance from the helicopter to the noise measuring point when the helicopter is directly over the centre noise measuring point and H_rK_r is the reference distance.

3.2.3.2.2 <u>Procedure for the determination of source noise adjustment</u>

For demonstration of overflight reference noise certification levels, off-reference adjustments shall normally be made by using a sensitivity curve of Maximum Tone Corrected Perceived Noise Level (PNLTM) versus advancing blade tip Mach number deduced from overflights carried out at different airspeeds around the reference airspeed. However, adjustment may be made by using an alternative parameter or parameters approved by the certificating authority. If the test aircraft is unable to attain the reference value of advancing blade tip Mach number or the agreed reference noise correlating parameter, then an extrapolation of the sensitivity curve is permitted, provided that the data cover a range of values of the noise correlating parameter between test and reference conditions as agreed by the certificating authority. The advancing blade tip Mach number, or agreed noise correlating parameter, shall be computed from as-measured data using true airspeed, on-board outside air temperature (OAT) and rotor speed. A separate curve of source noise versus advancing blade tip Mach number, or another agreed noise correlating parameter, shall be derived for each of the three noise certification measurement points (i.e. centre line, left sideline and right sideline). Left and right sidelines are defined relative to the direction of the flight for each run. PNLTM adjustments are to be applied to each microphone datum using the appropriate PNLTM function.

In order to eliminate the need for a separate source noise adjustment to the overflight test results the following test procedure is considered acceptable when the correlating parameter is the main rotor advancing blade tip Mach number (M_r).
Each overflight noise test must be conducted such that:

a) The adjusted reference true air speed (V_{ar}) is the reference airspeed (V_r) specified in 8.6.3 of Chapter 8 of the Annex adjusted as necessary to produce the same main rotor advancing blade tip Mach number as associated with reference conditions;

Note.- The reference advancing blade tip Mach number (M_r) is defined as the ratio of the arithmetic sum of the main rotor blade tip rotational speed (V_T) and the helicopter reference speed (V_r) divided by the speed of sound (c_r) at 25 °C (346.1 m/s) such that:

$$M_r = \frac{V_T + V_r}{c_r}\,,$$

and the adjusted reference true airspeed (V_{ar}) is calculated from:

$$V_{ar} = c\left(\frac{V_T + V_r}{c_r}\right) - V_T\,,$$

where c is the speed of sound calculated from the onboard measurement of outside air temperature (see 2.8).

b) The test true airspeed (*VT*) shall not vary from the adjusted reference true airspeed (*Var*) by more than ± 5 km/h (±3 kt) or an equivalent approved variation from the reference main rotor advancing blade tip Mach number (*Mr*);

c) In practice, the tests will be flown to an indicated airspeed which is the adjusted reference true airspeed (*Var*) corrected for compressibility effects and instrument position errors; and

d) The on-board outside static air temperature must be measured at the overflight height just prior to each overflight.

Note 1.- The calculation of noise levels, including the adjustments, is the same as that described in Chapter 8 and Appendix 2 of the Annex except that the need for source noise adjustment is eliminated. It should be emphasised that in the determination *of the duration adjustment (Δ_2), the speed component of the duration adjustment is calculated as 10 log(V_G/V_{Gr}) where V_G is the test ground speed and V_{Gr} is the reference ground speed.*

Note 2.- The symbol V_G is denoted as the symbol V and V_{Gr} as V_r in Chapter 8 of the Annex.

3.3 TECHNICAL PROCEDURES INFORMATION

3.3.1 Jet and propeller-driven aeroplanes

3.3.1.1 *Computation of EPNL by the Integrated Method of adjustment*

Section 9.1 of Appendix 2 of the Annex provides for the use of the "simplified" or "integrated" method for adjusting measured noise data to reference-day conditions. The "integrated" procedure may be applied to measured data at the flyover, lateral, and approach noise measurement points. With the "integrated" adjustment method, all data adjustments are applied to each measured set of sound pressure levels obtained at one-half second intervals in order to identify equivalent reference average sound pressure levels which are used to compute EPNL values consistent with values which would be obtained under reference conditions. For complete acoustic consistency the adjustment is only applicable if evaluated for identical pairs of noise emission angle (θ) relative to the flight path and for noise elevation angle (ψ) relative to the ground for both the measured (i.e. test) and adjusted (i.e. reference) flight paths. While this requirement may be satisfactorily approximated for the flyover and approach noise measurements, it can be shown that it is not possible to retain identical pairs of angles when lateral noise measurement adjustments are necessary. Therefore when lateral noise measurement adjustments are made by the "integrated" method, the geometric conditions of identical noise emission angle should be maintained for test and reference flight paths while the corresponding differences between test and reference elevation angles should be minimized. The slight difference that will occur between test and reference elevation angle will have negligible effect on the corrected EPNL value.

This section describes an integrated adjustment method that is applicable for use when the aeroplane is operated at constant conditions of flight path and power during the noise measurement period.

3.3.1.1.1 Test aircraft position

The "integrated" method for adjustment of measured noise level data to reference conditions requires noise and aeroplane performance data at each one-half second time interval during the test flights. These data include aeroplane position relative to a three-dimensional (*X*, *Y* and *Z*) coordinate system, one-third octave band sound pressure levels *SPL(i,k)*, and time (t_k) at the midpoint of each averaging time period relative to a reference time. Additionally, aeroplane performance parameters, the noise measurement points, and temperature and humidity are required for each flyover.

The aircraft height (*Z*) is measured above the reference *X-Y* plane, generally taken to be the ground plane, with the measurement microphone 1.2 m (4 ft) above this reference plane. The average test flight path is assumed to be a straight line, except when thrust (power) reduction is used during the flyover measurement, and the time-correlated aeroplane-position data are used to determine the time of overhead (t_{oh}), the test overhead height (h_{To})[2] and the test minimum distance (d_{Tm}) from the test flight path to the microphone location [$K (X_{TM}, Y_{TM}, Z_{TM})$].

[2] For emphasis, the subscript "T" is used here for test conditions. Annex 16 uses unsubscripted symbols for test conditions.

Using the test data directly or by geometric analysis of the relation between the average straight line flight path and the minimum distance line from K_T to R_T (X_{RT}, Y_{RT}, Z_{RT}) as shown in Figure 3-31, the minimum distance becomes:

$$d_{Tm} = [(X_{RT} - X_{TM})^2 + (Y_{RT} - Y_{TM})^2 + (Z_{RT} - Z_{TM})^2]^{1/2}$$

3.3.1.1.2 <u>Sound propagation times and sound emission angles</u>

The test sound propagation time (Δt_{pk}) is identified with the data record time (t_k), the noise emission time (t_{ek}), the aeroplane position (A_k) at time (t_{ak}), and the averaging time (t_{Av}) via the following relationships:

$$t_k = t_{ak} - ½t_{Av}$$

$$t_{ek} = t_k - \Delta t_{pk}$$

$$\Delta t_{pk} = K_T Q_{ek}/c_T,$$

where c_T is the speed of sound for the average absolute temperature of the air between the surface (T_S) and the height of the aeroplane (T_A) (see 2.8, where $T = (T_s + T_A) / 2$).

Using the geometric relationships of Figure 3-31, the minimum distance derived from the equation of 3.3.1.1.1, the test distance $Q_{ek}R$, and defining the time difference B equal to $t_{Tm} - t_k$ yields the following expression for the test flight path sound propagation times:

$$\Delta t_{Tpk} = [1/(c_T^2 - V_T^2)] \times \{BV_T^2 + [(c_T^2 - V_T^2)(d_{Tm})^2 + (Bc_TV_T)^2]^{1/2}\},$$

where V_T is the average true airspeed of the test aeroplane along the flight path.

Similarly, the test sound emission angle is defined as:

$$\theta_{ek} = \sin^{-1} (d_{Tm}/d_{Tpk}) \text{ , or}$$

$$\theta_{ek} = \sin^{-1} [d_{Tm}/(\Delta t_{Tpk})(c_T)].$$

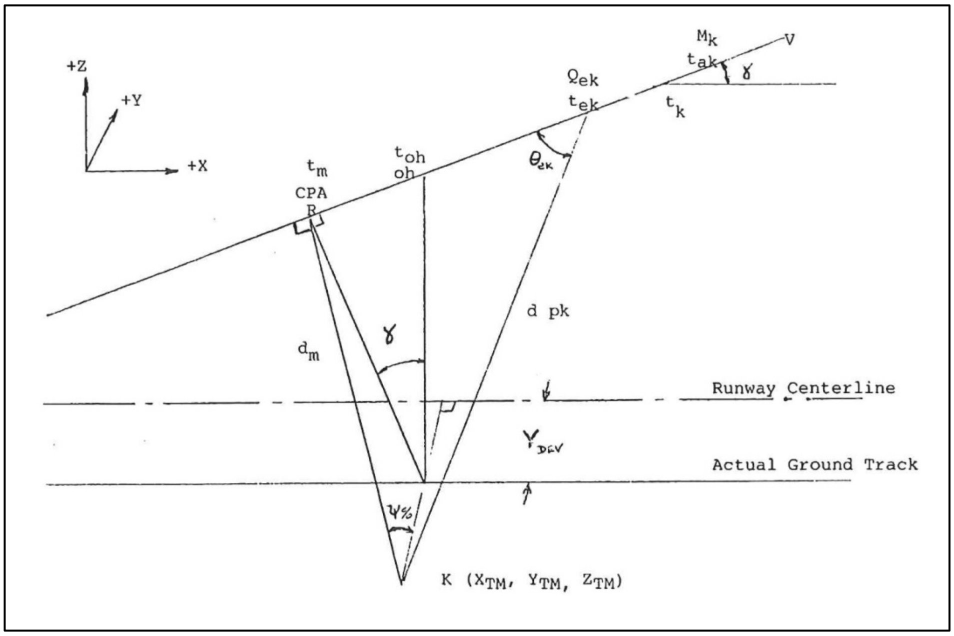


Figure 3-30 Geometry for integrated procedure

3.3.1.1.3 Aircraft reference flight path

The geometry of the reference flight path is essentially similar to that shown in Figure 3-30, except for the following differences:

a) The reference flight path is directly over the runway centre line (i.e. $Y_{DEV} = 0$).

b) For the take-off and approach flyovers, the measurement station is on the runway centre line (i.e. $Y_{rr} = Y_{rM}$); and

c) For lateral noise measurements, ($Y_{rr} – Y_{rM}$) equals the reference lateral displacement of the measurement station.

Note 1.- The subscript “r” is used to denote reference conditions.

Note 2.- The reference microphone location (K_r) for flyover or lateral noise measurements is usually at the same coordinates as for the test location (K_T), i.e. (X_{TM},, Y_{TM},, Z_{TM}) = (X_{rM},, Y_{rM},, Z_{rM}).

The reference flight path may be geometrically specified relative to the reference microphone location (K_r) by using the measurement station lateral distance, the height overhead (h_{ro}) and the flight path inclination angle (γ_r).

These values are equated to the minimum distance (d_{rm}) from K_r by the following equations:

$$d_{rm} = [h_{ro}^2 \cos^2 \gamma_r + (Y_{Rr} - Y_{rM})^2]^{1/2}\text{, or}$$

$$d_{rm}\ [(X_{Rr} - X_{rM})^2 + (Y_{Rr} - Y_{rM})^2 + (Z_{Rr} - Z_{rM})^2]^{1/2}\ .$$

The basic acoustic assumption relating the test and reference flight conditions is that the three dimensional acoustic emission angles (θ_{ek} and θ_{erk}) for each test record time (t_k) and the corresponding reference time (t_{rk}) are equal. Using the equation for θ_{ek} and this equality, the test sound pressure levels, $SPL_T(i, k)$, for each of the *i-th* frequency bands, are adjusted for spherical spreading and sound attenuation due to atmospheric absorption over the acoustic path lengths by the following equations:

a) $SPL_r(i, rk) = SPL_T(i, k) - 20 \log (d_{rpk}/d_{Tpk}) - [\alpha(i)_0\, d_{rpk} - \alpha(i)\, d_{Tpi}]$,

where $\alpha(i)_0$ and $\alpha(i)$ are the reference and test-day sound attenuation coefficients, respectively; or

b) when the test and reference flight path minimum distances are used, by the equation:

$SPL_r(i, rk) = SPL_T(i, k) - 20 \log (d_{rm}/d_{Tm}) - [\alpha(i)_0\, d_{rm} - \alpha(i)\, d_{Tm}] \operatorname{cosec} \theta_{ek}.$

3.3.1.1.4 Time interval computation

In addition to the above adjustments of the test data for spherical spreading and sound attenuation due to atmospheric absorption, it is necessary to make an adjustment for the change in the time increment t_{rk}, that is used in the computation of EPNL. Since the time increments when adjusted by the "integrated" method are not equal to the 500 ms test measurement time increments, successive aeroplane position reference times (t_{rk} *and* $t_{r(k+1)}$) occur after the time reference (t_{rek}) at the sound emission point (Figure 3-31). The average time increment to be used in the EPNL computation is:

$\delta t_{rk} = [\Delta t_{rk} + \Delta t_{r(k-1)}] / 2$,

where the reference time interval (Δt_{rk}) between data records is:

$\Delta t_{rk} = t_{r(k+1)} - t_{rk}$. .

Using the relationship between sample times, sound emission times and sound propagation times, the reference interval becomes:

$\Delta t_{rk} = [t_{re(k+1)} - t_{rek}] + [\Delta t_{rp(k+1)} - \Delta t_{rpk}]$.

This time interval reflects the time for the aeroplane to travel at test and reference speeds (V_T and V_r) from one sound emission point to the next, and also the effect of differences between test and reference minimum distances (d_{rm} and d_{Tm}) as well as sound speeds (c_r and c_T). These factors are expressed explicitly by arranging the equation above for Δt_{rk} as follows:

$$\Delta t_{rk} = (d_{rm}/d_{Tm})\ \{(V_T/V_r)[0.5 - (\Delta t_{Tp(k+1)} - \Delta t_{Tpk})] + (c_T/c_r)\ (\Delta t_{Tp(k+1)} - \Delta t_{Tpk})\}.$$

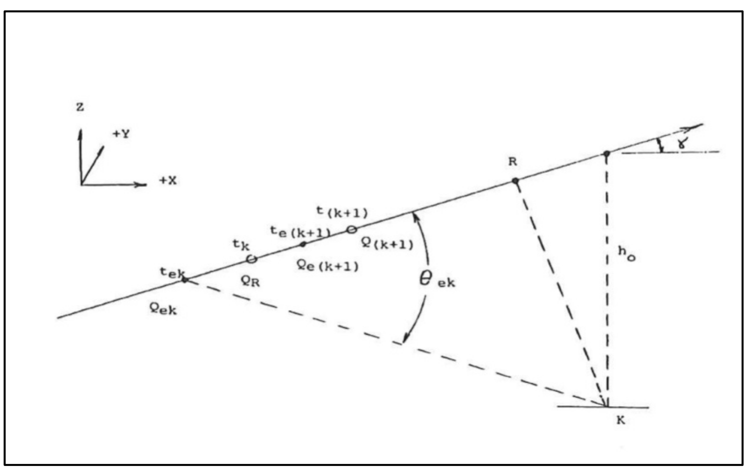


Figure 3-31 Relative time periods for integrated procedure

3.3.1.1.5 Adjusted EPNL

After the sound pressure levels have been adjusted by using the equation given above, the tone corrections are calculated according to 4.3 of Appendix 2 of the Annex. In addition, using the noy weighting and the procedure for calculating Perceived Noise Level (PNL) (see 4.2 of Appendix 2 of the Annex), the reference Tone Corrected Perceived Noise Levels (PNLT) are available for the times t_{r1} to t_{rn} which include the first and last 10 dB-down times. These values and the adjusted average time increment $\delta\, t_{rk}$ (see 3.3.1.1.4) are then combined to compute the adjusted EPNL as follows:

$$EPNL = 10\log\left[\left(\frac{1}{T_0}\right)\sum_{k=1}^{n}\left(10^{0.1PNLT_k}\right)\left(\delta t_{rk}\right)\right] ,$$

where the reference time (T_0) is 10 s and the summation is started by setting $\Delta t_{r\,(1-1)} = \Delta t_{r\,(2-1)}$ so that $\delta\, t_{r\,(1-1)} = \Delta t_{r1}$.

The summation is terminated by assuming Δtrn = Δtr (n – 1) giving δtrn = Δtrn = Δtr (n – 1).

In practice the adjusted EPNL value is calculated via a summation from the first 10 dB-down point, kF, to the last 10 dB-down point, kL, of the contributions of sound energy associated with each individual time increment (record). Note that the duration associated with each record, δtrk, is not uniform (see 3.3.1.1.4). Table 3-4 provides an example of how this calculation can be performed.

Labels	$PNLT_k$	δt_{rk} s	"Energy" $= \left(10^{(0.1 PNLT_k)}\right)\delta t_{rk}$
	84.62	0.3950	
	85.84	0.3950	
	85.37	0.3951	
k_F	88.57	0.3951	284254291.2
	88.82	0.3952	301173624.8
	88.03	0.3953	251146317.4
	88.76	0.3954	297191692.3
	87.06	0.3956	201027875.5
	86.92	0.3957	194700044.3
	90.39	0.3960	433206721.0
	89.89	0.3963	386388393.4
	91.00	0.3967	499415710.9
	90.08	0.3973	404686358.5
	89.71	0.3981	372384998.9
	89.61	0.3992	364914006.0
	90.21	0.4009	420761559.6
	91.14	0.4033	524358390.8
	92.10	0.4066	659427985.6
	93.68	0.4108	958584572.0
	94.89	0.4153	1280447955.7
	95.87	0.4196	1621195835.7
	97.06	0.4231	2150022601.5
PNLTM	97.40	0.4256	2338845959.1
	96.23	0.4273	1793630138.6
	94.73	0.4285	1273358894.6
	92.30	0.4294	729225824.4
	88.75	0.4299	322379520.6
k_L	86.96	0.4304	213733335.2
	85.41	0.4307	
	83.88	0.4309	
	83.01	0.4311	
		Total Energy	18276462607.5

EPNL$=10\log(TotalEnergy)-10$	92.61892

Table 3-4 Example calculation of adjusted EPNL value when using the integrated method of adjustment.

3.3.2 Jet aeroplanes

3.3.2.1 *Control of noise certification computer program software and documentation related to static-to-flight projection processes*

3.3.2.1.1 General

Procedures for computer program software control shall be developed, approved by the certificating authority, and maintained and adhered to by each applicant utilizing "static-to-flight equivalencies (SFE's).

The procedures shall consist of four key elements which, when implemented by the noise certification applicant, shall result in documentation which properly describes and validates the applicable SFE noise certification computer program and data output. Throughout the development of a given aeroplane type, adherence to these procedures will enable the tracking of critical computer programs in order to verify that the initial software design has not been changed without substantiation.

The four key elements of configuration index, software control plan, design description and verification process are described in 3.3.2.1.2.

3.3.2.1.2 Software control procedures - four key elements

3.3.2.1.2.1 *Configuration index*

A configuration index shall be established for each unique SFE software system. It will include all applicable elements of the software system and provide historic tracking of documents and software under control. Where appropriate, the index may be maintained in a general database.

3.3.2.1.2.2 *Software control plan*

A procedure for SFE software change management shall be established that includes the baseline design identification, a software change control system and a method of reviewing and auditing software changes and maintaining a status accounting of changes.

Control of software changes shall be maintained by establishing baselines within the verification process described below and by documenting modifications to the baseline case that result from program coding changes. Review and auditing procedures will be established within the verification process to allow the validity of the program coding changes for the "modified" configuration to be assessed relative to the "baseline" configuration.

The configuration index shall be updated to reflect, historically, the changes made to the software system.

3.3.2.1.2.3 *Design description*

A technical description of the methods used to accomplish the SFE certification shall be provided, including an overview and a description of the software system design to accomplish the technical requirements. The software design description should include the program structure, usage of subroutines, program flow control and data flow.

3.3.2.1.2.4 *Verification process*

The validation process for the SFE software system, or modifications to it, shall include a procedure to verify that the calculations described in the documentation are being performed properly by the software. The process may include manual calculations compared to computer output, stepwise graphical displays, software audits, diagnostic subroutines that generate output of all relevant variables associated with the modifications, or other methods to establish confidence in the integrity of the software. The process results shall be monitored and tracked relative to software calculation changes.

3.3.2.1.3 Applicability

Although the software control plan is applicable to all SFE-specific computer program software and documentation established through the specific procedures and processes of each applicant, it may not be necessary to review and audit ancillary software such as, but not limited to, subroutines dealing with the sound attenuation coefficients for the effects of atmospheric absorption, noy calculations and tone corrections for each main program source code change.

3.3.2.2 *Identification of spectral irregularities*

3.3.2.2.1 Introduction

Spectral irregularities which are not produced by aircraft noise sources may cause tone corrections to be generated when the procedures of 4.3 of Appendix 2 of the Annex are used. These spectral irregularities may be caused by:

a) The reflected sound energy from the ground plane beneath the microphone mounted at 1.2 m (4 ft) above it, interfering with the direct sound energy from the aircraft. The re-enforcing and destructive effects of this interference are strongest at lower frequencies, typically 100 Hz to 200 Hz and diminish with increasing frequency. The local peaks in the one-third octave spectra of such signals are termed pseudotones. Above 800 Hz this interference effect is usually insufficient to generate a tone correction when the Annex 16 tone correction procedure is used;

b) Small perturbations in the propagation of aircraft noise when analysed with one-third octave bandwidth filters; or

c) The data processing adjustments such as the background noise adjustment method and the adjustment for sound attenuation due to atmospheric absorption. In the case of the latter, the sound attenuation coefficients (a) given in Reference 11 ascribe values at 4 kHz to the centre frequency of the one-third octave band whereas at 5 kHz the value of a is ascribed to the lower pass frequency of the one-third octave. This difference is sufficient in some cases to generate a tone correction.

The inclusion of a tone correction factor in the computation of Effective Perceived Noise Level (EPNL) accounts for the subjective response to the presence of pronounced spectral irregularities. Tones generated by aircraft noise sources are those for which the application of tone correction factors is appropriate. Tone correction factors which result from spectral irregularities (i.e. false tones produced by any of the causes cited above) may be disregarded. This section describes methods which have been approved for detecting and removing the effects of such spectral irregularities. Approval of the use of any of these methods however remains with the certificating authority.

3.3.2.2.2 Methods for identifying false tones

3.3.2.2.2.1 *Frequency tracking*

Frequency tracking of flyover noise data is useful for the frequency tracking of spectral irregularities. The observed frequency of aeroplane noise sources decreases continuously during the flyover due to Doppler frequency shift, f_{DOPP}, where:

$$f_{DOPP} = \frac{f}{1 - M\cos\lambda},$$

where:

- f is the frequency of the noise at source;
- M is the Mach number of the aeroplane; and
- λ is the angle between the flight path in the direction of flight and a line connecting the source and observer at the time of emission.

Reflection-related effects in the spectra (i.e. pseudotones) decrease in frequency prior to, and increase in frequency after passing overhead or abeam the microphone. Spectral irregularities caused by perturbations during the propagation of the noise from the aeroplane to the microphone tend to be random in nature, in contrast to the Doppler effect. These differing characteristics can be used to separate source tones from false tones.

3.3.2.2.2.2 *Narrow-band analysis*

Narrow-band analysis with filter bandwidths narrower than those of one-third octaves is useful for identifying false tones. For example, when the analysis is produced such that the spectral noise levels at an instance are presented in terms of image intensity on a line, the overall flyover analysis clearly indicates the Doppler-shifted aeroplane tones and those due to reflection as described above.

3.3.2.2.2.3 *Microphone mounting height*

Comparison of one-third octave spectra of measurements taken using the 1.2 m (4 ft) high microphone and corresponding data obtained from a neighbouring microphone mounted flush on a hard reflecting surface (a configuration similar to that described in 4.4 of Appendix 6 of the Annex) or at a height substantially greater than 1.2 m (4 ft), such as 10 m (33 ft), may be used to identify false tones. Changes to the microphone height alter the interference spectra irregularities from the frequency range of data from the 1.2 m (4 ft) high microphone, and when a comparison is made between the two data sets collected at the same time, noise source tones can be separated from any false tones which may be present.

3.3.2.2.2.4 *Inspection of noise time histories*

Spectral irregularities which arise following data adjustment as described in this section will occur in the frequency range of between 1 kHz to 10 kHz and the resulting false tone corrections will normally vary in magnitude between 0.2 dB to 0.6 dB. Time histories of Perceived Noise Levels (PNL) and Tone Corrected Perceived Noise Levels (PNLT), which exhibit constant level differences, are often indicative of the presence of false tone corrections. Supplementary narrow-band analysis is useful in demonstrating that such tone corrections are not due to aeroplane-generated noise.

3.3.2.2.3 Treatment of false tones

When spectral irregularities give rise to false tones which are identified by, for example, the methods described in this section their values, when computed according to Step 9 of the tone correction calculation described in 4.3 of Appendix 2 of the Annex, may be set to zero.

3.3.2.3 *Noise data adjustments for tests at high altitude test sites*

3.3.2.3.1 Introduction

Jet noise generation is somewhat suppressed at higher altitudes due to the difference in the engine jet velocity and jet velocity shear effects resulting from the change in air density. The use of a high altitude test site for the noise test of an aeroplane model that is primarily jet noise dominated should include making the following adjustments. These jet source noise adjustments are in addition to the standard pistonphone barometric pressure adjustment of about 0.1 dB/100 m (0.3 dB/1000 ft) which is normally used for test sites not approximately at sea level. The jet source noise adjustments are applicable to tests conducted at sites at or above 366 m (1200 ft) mean Sea Level (MSL).

3.3.2.3.2 Jet noise source adjustment

Flight test site locations at or above 366 m (1200 ft) MSL, but not above 1219 m (4000 ft) MSL, may be approved provided certain criteria are met (see Figure 3-32) and the source noise adjustments are applied.

Alternative criteria or adjustments require the approval of the certificating authority.

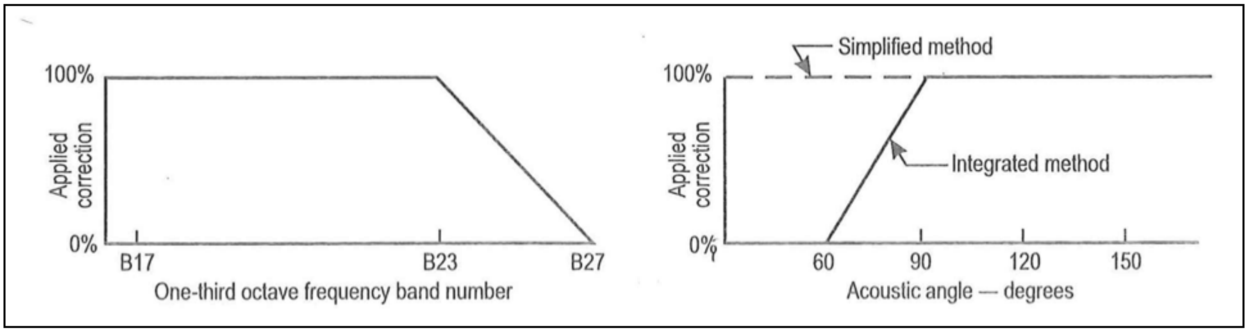


Figure 3-32 Criteria for jet noise source correction

3.3.2.3.2.1 Criteria

Jet source noise altitude adjustments are required for each one-half second spectrum when using the integrated procedure, and for the Maximum Tone Corrected Perceived Noise Level (PNLTM) spectrum when using the simplified procedure (see 9.3 and 9.4 of Appendix 2 of the Annex) and are to be applied in accordance with the criteria described in Figure 3-32

3.3.2.3.2.2 Adjustment procedures

An acceptable jet source noise adjustment is as follows:

a) Adjust each one-half second spectrum or PNLTM one-half second spectrum, as appropriate, in accordance with the criteria of 3.3.2.3.2.1 by using the following equation:

$$\Delta SPL = [10 \log (d_R/d_T) + 50 \log (c_T/c_R) + 10k \log (u_R/u_T)]\ [F1]\ [F2]$$

where:

– Subscript T denotes conditions at the actual aeroplane test height above MSL under standard atmospheric conditions (i.e. ISA+10ºC (50°F) and 70 per cent relative humidity);

– Subscript R denotes conditions at the aeroplane reference height above MSL (i.e. aeroplane test height above MSL minus the test site altitude) under standard atmospheric conditions (i.e. ISA+10ºC (50°F) and 70 per cent relative humidity);

– SPL denotes sound pressure level;

– d_R is the density for standard atmosphere at the aeroplane reference height in kg/m^3 (lb/ft^3);

– d_T is the density for standard atmosphere at the aeroplane test height in kg/m^3 (lb/ft^3);

– c_R is the speed of sound corresponding to the absolute temperature for a standard atmosphere at the aeroplane reference height in m/s (ft/s);

– c_T is the speed of sound corresponding to the absolute temperature for a standard atmosphere at the aeroplane test height in m/s (ft/s);

– $k = 8$, unless an otherwise empirically derived value is substantiated;

– $u = (v_e - v_a)$ is the equivalent relative jet velocity in m/s (ft/s)

where:

– v_e is the equivalent jet velocity as defined in Appendix C of Reference 14, and obtained from the engine cycle deck in m/s (ft/s); and

– v_a is the aircraft velocity in m/s (ft/s).

– u_R is the equivalent relative jet velocity in m/s (ft/s) where v_e is determined at $N1C_{TEST}$ for standard atmosphere at the aeroplane reference height;

– u_T is the equivalent relative jet velocity in m/s (ft/s) where v_e is determined at $N1C_{TEST}$ for standard atmosphere at the aeroplane test height;

– *N1C* is the corrected engine rpm $N_1/\sqrt{\theta_{t_2}}$

– *F1* is a factor corresponding to the percentage of applied adjustment related to acoustic angle in Figure 3-32 (values range from 0.00 to 1.00); and

– *F2* is a factor corresponding to the percentage of applied adjustment related to the one-third octave band in Figure 3-32 (values range from 0.00 to 1.00);

b) for each one-third octave band SPL, arithmetically add the height jet noise adjustment in 3.3.2.3.2.2a to the measured SPLs to obtain the altitude jet source noise adjusted SPLs for the derivation of Perceived Noise Level described in 4.1.3a of Appendix 2 of the Annex; and

c) the height adjustment is to be applied to all measured test data including approach conditions unless it can be substantiated that the jet noise during approach does not contribute significantly to the total aircraft noise.

3.3.2.4 *Acquistion of in-duct and/or near-field data for demonstration of "No-Acoustical Change" (NAC)*

3.3.2.4.1 General

Certificating authorities have found it acceptable for applicants to conduct noise tests to evaluate minor engine changes of the types described in 3.2.1.2.2. Frequently the objective for these tests is to provide evidence that the changes involved produce negligible impact on EPNL noise values and may therefore be categorized as NACs relative to the certificated aircraft configuration. Such testing has included component tests, static engine tests in a test cell, near-field microphone measurements, and in-duct dynamic pressure measurements.

3.3.2.4.2 Guiding principles

The overall guiding principles to be followed in providing acceptable evidence for substantiation of engine NACs are:

a) the measurements and analyses should adequately model the noise such that small changes in aircraft noise levels can be quantified; and

b) the noise measurement technique and the test environment should not introduce changes to the noise sources that invalidate the predicted small changes in aircraft noise levels.

These guiding principles should be applied in all cases, with details of the approach being justified on a case-by-case basis as appropriate.

Note 1.- It is important that the near-field or in-duct measurements enable a sufficiently accurate prediction of the changes to engine noise in the far-field.

Note 2.- It is important that the noise generating mechanisms of interest are not significantly affected by the test cell environment. The test cell should have an exhaust collector to minimize re-circulation. There should be insignificant inlet distortion or inflow turbulence, or a turbulence control screen or inflow control device should be employed to minimise such distortions or turbulence. Test cell measurements might not be appropriate for assessing jet noise changes because of the influence of the test cell on the jet development.

Note 3.- Care must be taken to ensure the noise source under investigation is not masked by other unrepresentative noise components. Whilst a reduced acoustic standard of components not under investigation might be acceptable in many cases, there are examples where such differences might invalidate the premise of a NAC (e.g. noise from the intake being masked by a hard-walled bypass duct or significant noise from an overboard air dump contaminating the measured noise).

3.3.2.4.3 Measurement systems

Typical measurement systems used to acquire data for substantiation of an engine NAC include:

a) near-field microphones, either in test cells or out-door facilities;

b) in-duct transducer measurements in the fan inlet or exhaust duct; and

c) core probes to assess combustor or low pressure turbine design changes.

3.3.2.4.4 Measurement and data analysis procedures

The measurement and data analysis process should be accomplished on the basis of the following criteria:

a) An adequate array of transducers should be used to ensure that the measurements adequately model the noise. To determine overall changes in sound pressure level the measured noise levels will typically need to be averaged azimuthally, radially and/or axially in order to avoid false conclusions being drawn from anomalous readings from single transducers;

b) It should be ensured that changes in the local environment (e.g. test cell temperature) do not result in significant anomalies in the measured noise differences;

c) Microphones should be mounted on the test cell wall or on the ground or floor, but not in the shadow of any support structures or other test hardware;

d) In-duct transducers should be flush mounted with minimal loss of area of acoustic treatment. Rake-mounted transducers in the flow path should be avoided if they shed wakes that impinge on downstream structures and thereby create significant noise;

e) Core probes should be fixed securely to the pylon, boat-tail fairing or other support and not be excessively buffeted by the flow;

f) The specifications of the measurement system and calibration procedures for microphones, recording and reproducing systems should be in accordance with section 3 of Appendix 2 of the Annex. Laboratory calibrations of in-duct transducers and core probes should be conducted before and, if possible, after each test. The dynamic range of the transducers should be sufficient to avoid overload;

g) Data should be acquired over the relevant engine operating speeds and for all relevant combinations of engine variables, as specified in the latest version of Reference 10 (see 3.2.1.3.3.1);

h) The interpretation of in-duct measurements should take into account the possibility that decaying or cut-off acoustic waves may be present that may mask changes sensed in the far field of the propagating wave; and

i) Two alternative methods could be used in the subsequent analysis of the measured noise levels to demonstrate a NAC:

   – The measured component noise changes could be incorporated into a noise model that predicts the aircraft EPNL. This method has the added value of taking into account in-flight effects and the relative significance of the different noise sources; or

   – In some circumstances, it might be possible to reach the conclusion of a NAC without the need to incorporate the measured component noise changes into a noise model that predicts aircraft EPNL. The measured noise changes could be examined to see if there is no increase in noise levels at any relevant frequency or engine condition.

Generally, noise models that predict the aircraft noise level expressed in EPNL are based on far field static test data. Consequently, in either analysis it will be necessary to agree with the certificating authority the method for calculating the impact on far field static noise resulting from near field microphone measurements or in-duct transducer measurements. This will normally require sound engineering judgement, seeking out patterns in the data and technical explanations for any observed differences.

Furthermore the statistical (un)certainty in the data should be considered. For example if statistical analysis shows that the uncertainty in the data is large and the differences are small, then no conclusions can be drawn from the data. On the other hand if the tests show large decreases in noise levels that outweigh the uncertainty in the data it may be possible to conclude, with reasonable certainty, that the changed engine is indeed quieter than the original engine.

Chapter 4

GUIDELINES FOR PROPELLER-DRIVEN AEROPLANES NOT EXCEEDING 8618 kg EVALUATED UNDER APPENDIX 6 OF ICAO ANNEX 16, VOLUME I

4.1 EXPLANATORY INFORMATION

4.1.1 Noise certification test and measurement conditions

AMC A6 2.1
[General]

(1) Applicant's Responsibility

An applicant should prepare a noise compliance demonstration plan as described in 1.4 that specifies a proposed certification process, including equivalencies. This plan is to be submitted to the appropriate certificating authority allowing sufficient time to permit adequate review and possible revisions prior to the start of any noise certification testing.

GM A6 2.2.1
[Test Site Selection]

Section 2.1 provides a description of the technical procedures that applicants should follow in selecting a noise certification test site for propeller-driven aeroplanes not exceeding 8618 kg and evaluated under Appendix 6 of the Annex.

GM A6 2.2.2
[Meteorological Conditions]

(1) Precipitation

Fog, rain, drizzle, and snow can have a number of adverse effects. Changes in sound generation and propagation under these conditions are not well documented. Most of the equipment used for measuring noise is not intended for use during conditions of precipitation, and the effects can range from changes in microphone and windscreen sensitivity or frequency response, to arcing of conventional condenser microphones, to possible failure of equipment because of electrical short circuits.

(2) Atmospheric Conditions

Atmospheric conditions can affect the generation and propagation of sound, for non-reference helical tip Mach numbers (see 5.2.1 of Appendix 6 of the Annex). Propellers generate higher noise levels at higher propeller helical tip Mach numbers. Usually the actual tip velocity is close to reference propeller tip velocity, but the speed of sound is a function of air temperature which is often different than the reference value. Off-reference tip Mach numbers can occur because of off-reference air temperature. The Annex specifies the need for correction for non-reference tip Mach numbers under most circumstances. However, limiting the permissible test temperature range reduces the potential magnitude of this correction. Corrections are also required to account for non-reference atmospheric absorption of sound. The magnitude of this correction is also limited by restricting the range of permissible temperature and relative humidity.

(3) Non-uniform Atmosphere

The atmosphere between the source (i.e. aeroplane, propeller, and/or exhaust) and the microphone is not uniform. There can be strong temperature gradients, positive and negative, variations in relative humidity, and variation in wind. Turbulence is also associated with strong winds, which can cause irregular sound propagation. Corrections are not required to account for wind. The wind limits only provide a means of determining acceptability of the data.

(4) Weather Monitoring

Based on the above considerations, weather conditions should be monitored. Procedures used in the noise certification process for transport category aeroplanes and turbojet-powered aeroplanes call for measurement of the weather conditions between the ground and the height at which the aeroplane is flying (see 2.2.2.2b of Appendix 2 of the Annex). The absorption of sound in air can then be computed based on these measurements. This process requires an appreciable investment of time and resources. For light propeller-driven aeroplanes, the magnitude of the adjustment for atmospheric absorption is less than that for jet aeroplanes. An adjustment procedure based on measurements of the weather near the surface is therefore considered sufficient and more appropriate for aeroplanes covered by this section.

(5) Temperature Inversions

The effects of inversions and anomalous wind conditions are difficult to quantify. When temperature inversions are present (i.e. when the air temperature increases with height over any portion of the atmosphere between the ground and the aeroplane) flight conditions may be unstable, which hampers the ability of the pilot to set up a consistent, stabilized climb within the permitted operational tolerances. Also, under these conditions, it is possible to have a situation in which the surface temperature and relative humidity meet the permissible test criteria but the conditions aloft are much drier, with consequent high sound absorption characteristics and the possibility of underestimating the noise level . The noise spectrum of propeller-driven aeroplanes contains relatively less high-frequency noise than that of jet aeroplanes, so the effects may not be very significant unless there is a severe inversion.

AMC A6 2.2.2
[Atmospheric Measurements]

(1) General Weather Measurements

The applicant should measure weather conditions near the surface and in the vicinity of the noise measuring point. The acceptability of noise data is contingent on the conditions being within the specified limits of 2.2.2 of Appendix 6 of the Annex. These measurements are to be made at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground level. This allows the use of hand-held equipment but does not preclude the use of more complex equipment of the type identified in Appendix 2 of the Annex if the applicant so chooses. The weather data may be recorded on a chart, or a certificating authority witnessed record of the observations may be kept.

(2) Wind

Consistent with the less complex requirements for small propeller-driven aeroplanes, wind measurements may be made using a hand-held device if its specifications comply with the provisions of 2.2.2.1 of Appendix 2 of the Annex. If the device used does not provide enough information to compute the crosswind, then the wind in any direction should be limited to the crosswind limit of 9 km/h (5 kts). The wind limits are based on a 30s average.

(3) Temperature and Relative Humidity Limits

Noise data are acceptable only if the air temperature is in the range from 2º C (36° F) to 35º C (95° F), and the relative humidity is in the range from 20 to 95 per cent. Temperature and relative humidity may be measured with a psychrometer, a device that measures wet and dry bulb temperatures of the air. Relative humidity is then computed from these temperatures. Sufficient measurements should be made to determine all adjustments specified by

Appendix 6 of the Annex. Persons responsible for performing the test should be alert to changes in the conditions. At a minimum, measurements should be made immediately before the first run in a series and immediately after the last run. This interval should not exceed more than 1 hour because of the requirement for adjustment of the aeroplane test mass due to fuel loss. In marginal or changing conditions, shorter intervals would be more appropriate.

(4) Use of Airport Facility

Section 2.2e of Appendix 6 of the Annex also permits the use of airport facility weather-measuring equipment. In deciding if the equipment is acceptable verify that the measurements are representative of the conditions near the microphone, that the equipment is providing reliable information, that the equipment has recently been calibrated and that the equipment is approved by the certificating authority.

(5) Anomalous Winds

The presence of anomalous wind conditions may be assessed by noting the airspeed variation as the aeroplane climbs. If the wind is uniform or changes speed or direction slowly with altitude, there is no difficulty in maintaining a constant climb speed. If there are strong variations in the wind (i.e. wind shear) or rising and descending air, there will be variations in airspeed that are not easily controllable. Variations of ± 9 km/h (± 5 kts) during the overflight relative to the reference velocity (Vy) are permitted by Appendix 6 of the Annex and this criterion may be used to evaluate the presence of anomalous wind conditions.

(6) Air Temperature Measurements vs. Altitude

At the beginning of the test and, if considered necessary, at intervals during the test, an observer on the test aeroplane may consider monitoring the air temperature during a climb. This climb may be a noise data–recording climb or may be dedicated to temperature measurement. The information shall be assessed if a judgment is to be made about the acceptability of the conditions for noise measurements. The presence of anomalous wind conditions can be assessed during the data acquisition.

GM A6 2.3.5
[Aeroplane Flight Path]

(1) Aeroplane Position

Chapter 10 of the Annex specifies determination of the noise level at a single location relative to the start of take-off roll. Limits on the permissible deviation from the reference flight path (see Figure A6-1 of Appendix 6 of the Annex) are specified for the flight tests. These limits are based on the ability to obtain consistent, representative results, without placing excessive restrictions on the flight test. The initial take-off mass should be equal to the maximum approved take-off mass, and after an hour of flight time, the mass is to be increased back to maximum to account for fuel burn. This procedure ensures that the flight parameters, primarily angle of attack, do not vary significantly from the reference. The aeroplane position is to be approved by the certificating authority for each test overflight.

4.1.2 Noise unit definition

GM A6 3.0
[A-Weighting]

(1) Basis of Measurement

The A-weighting correction curve has been precisely defined by national and international standards for the measurement of sound such as environmental noise, and is a standard feature in sound level meters and other sound analysis equipment used for noise assessments.

4.1.3 Measurement of aeroplane noise received on the ground

GM A6 4.2
[System Calibration]

(1) Field Calibrations

It is possible to calibrate measurement and recording systems in a laboratory, and in fact this is usually done. However various circumstances, such as differing environmental conditions, may cause minor changes in equipment sensitivity. Unintentional damage may also occur during equipment setup and noise testing. Thus, field calibrations should be made.

AMC A6 4.2
[System Calibration]

(2) Acoustic Calibrations

An acoustic calibrator should be used to calibrate the measurement and recording system. The root-mean-square value of the calibration signal should be reported. Calibration signals are to be recorded on the tape recorder, if used, at the beginning and end of each test series and, at intervals approved by the certificating authority, throughout the test when there may be any delay in the performance of the test. The system should be allowed to reach a stable operating condition in accordance with the manufacturer's recommendations prior to the initial calibration.

GM A6 4.3.1
[Recording Systems]

(1) Audio Recorders

An audio recorder can be used to preserve a complete acoustical record of the events. If there are questions about the data observed during the tests, the recorded data can be replayed, multiple times if necessary, to verify the results. A more detailed analysis of the aeroplane noise signal may also be useful to the applicant for research and development purposes.

(2) Graphic Level Recorders

A graphic level recorder can be used to provide a permanent record of the noise levels, but no replay or reproduction of the acoustical signal is possible.

(3) Sound Level Meters

The record that results from the use of a sound level meter depends on the design features of the instrument. The least complex instrument uses an electromechanical metering mechanism, requiring the operator to observe the highest level indicated by the moving needle in the meter display during each event. Other, more complex instruments can be set to hold the maximum noise level reached during each event and show this level on a digital display. Some currently available digital units are capable of storing entire time-histories of noise levels for multiple runs. These histories can be recalled to the instrument's display, transmitted to a printer, or downloaded to a computer.

AMC A6 4.3.1
[Recording Systems]

(1) Audio Recorders

One method is to record each noise event using an audio recorder. This recorded data can be played back and analyzed as much as necessary to verify that consistent results have been obtained.

(2) Other Methods

Other methods include the following:

a) Reading graphic level recorder charts;

b) Reading a sound level meter in the field as the event occurs and keeping a handwritten log in ink; and

c) Printing, or transferring to a personal computer, the entire time-history after the test has been completed.

Appropriate measures should be taken to ensure the validity of the data, and their use is subject to approval by the certificating authority.

GM A6 4.3.4
[Noise Characteristics]

(1) Filtered Noise Level and Meter Response Speed

The noise level from each flyover test should be measured in terms of the maximum A-weighted sound level, in decibel (dB(A)) units, using an A-weighting filter with dynamic characteristics (meter response characteristics) designated as "S" (for "slow") as defined in Reference 20 and specified in section 3 of Appendix 6 of the Annex. The Slow response results in an effective 2s averaging period (i.e. 1s time constant), which should be used in Appendix 6, Annex 16, noise tests.

(2) Maximum Sound Level

The measured or indicated A-weighted sound level will increase as the aeroplane approaches the measurement site and will decrease after the aeroplane passes over the site. The highest value of the A-weighted sound level that occurs during the overflight is called the maximum A-weighted sound level. This is the value that should be measured during each test.

Note.- This maximum value may not occur at the exact moment when the aeroplane is directly over the microphone. It usually occurs slightly before or after the aeroplane reaches the overhead position due to the directivity characteristics of propeller, engine, and exhaust noise emissions.

GM A6 4.3.5
[Measurement System Sensitivity]

(1) Noise Level Variability

There can be variability in the noise levels indicated by the test equipment, primarily due to environmental factors and the internal warm-up that is required by most types of equipment. Occasionally, there may be other changes due to cable problems or even equipment damage. Proper use of acoustic calibration devices can help identify such occurrences.

AMC A6 4.3.5
[Calibration Process]

(1) Equipment Calibration

A suitable acoustic calibrator should be used to provide a reference sound level. This is usually accomplished by placing the calibrator on the microphone and adjusting the gain of the measuring system so that the reading corresponds to the known sound level of the calibrator. Initial, final, and periodic calibrations should be used to verify that any changes in sensitivity are identified. It is important that the manufacturer's recommended system warm-up time be observed in the field prior to equipment calibration. Calibration equipment should be identified in the test plan and is to be approved by the certificating authority.

GM A6 4.4.1
[Microphone Configuration]

(1) Ground Plane Microphone

The specified ground plane microphone configuration greatly minimizes the interference effects of reflected sound waves inherent in pole-mounted microphone installations. For a 1.2 m (4 ft) microphone, such effects typically occur in the frequency region that is most significant for propeller-driven aircraft noise.

(2) Microphone Sensitivity

The specified ground plane configuration places the microphone diaphragm into an effective sound pressure field for the frequency range of interest. Microphones designed for uniform pressure response are appropriate for use in such installations.

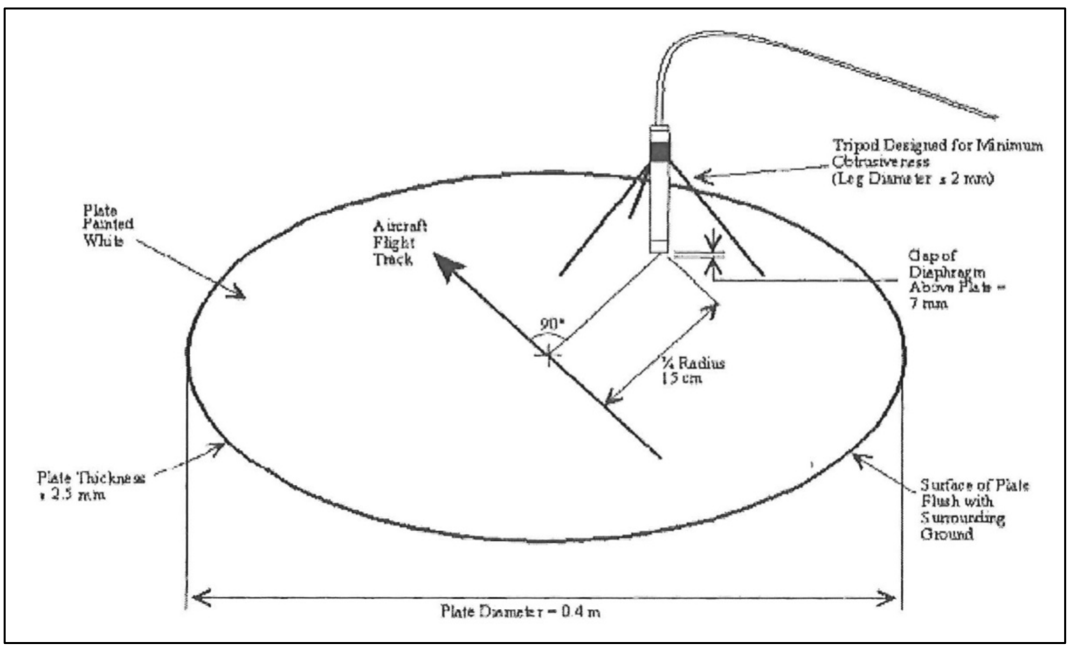


Figure 4-1 Configuration for 1/2 in. Inverted Microphone

AMC No. 1 A6 4.4.1
[Microphone Configuration]

(1) Inverted Microphone

The inverted microphone setup shown in the Figure 4-1 is an example of the design and construction of the microphone holder and the ground plate. The legs of the microphone holder should be firmly attached to the plate so that the microphone holder does not vibrate during the test. The plate should be painted white to reflect the sun's rays, as such reflection will reduce the thermal effects on the microphone-sensing element. A metal spacer is a practical tool to use in setting the space between the microphone diaphragm and the ground plate. The spacer thickness should be 7 mm minus the space between the microphone protective grid and the microphone diaphragm.

(2) Microphone Placement

The spacing of the microphone diaphragm relative to the plate is critical, since it should be inserted completely within the effective sound pressure field, and the depth of this field varies with frequency and sensor size. For frequencies of interest, the 7mm spacing has been determined to provide the best compromise of associated technical considerations.

AMC No. 2 A6 4.4.1
[Microphone Installation]

(1) Plate Installation in Local Ground Surface

Care should be taken during installation to ensure that the ground surface beneath the plate is level and contains no voids or gaps. One way to achieve this is by pressing the plate into the ground surface at the desired location, applying slight pressure, then removing the plate to determine if any areas under the plate are recessed. These recesses can then be filled-in with loose material, such as sand or soil, to obtain a level, uniform underlying surface. Care should also be taken to ensure that the edges of the plate are flush with the surrounding ground surface. This is especially important for plates that are thicker than the specified minimum of 2.5 mm.

In some cases it may be appropriate to moisten the soil with water immediately before installation, to allow the surface to mold itself around the plate. In such cases, acoustical measurements should not be performed until the ground has dried.

(2) Design and Construction of Microphone Support

The support should be designed so that it minimizes any potential interference with sound waves from the aircraft arriving in the vicinity of the microphone. If a spider-like structure such as that in the diagram above is used, the number of legs should be limited to three or four. As specified in the above diagram, the legs should be no larger than 2 mm in diameter. Ideally the support collar should be as small as possible, and it should also implement some sort of tightening device, such as a set screw, to facilitate adjustment of the microphone diaphragm height above the plate. The support should be stable and should orient the microphone in such a way that the diaphragm is parallel to the plate.

(3) Cable Support

In some cases, it may be desirable to provide additional support to the microphone cable as it leads away from the plate. A metal rod or similar sort of support may be used for this purpose. Any such support should be as small as possible and located as far away from the plate as is practical. The microphone cable should lead directly away from the plate without crossing above any more of the plate's surface than is necessary.

(4) Windscreens

Consideration should be given to using windscreens when wind speed exceeds 9 km/h (5 kts) (see 4.2.2).

AMC A6 4.4.4
[Background Noise Alleviation]

(1) Increased Aeroplane Noise

If a site with lower noise levels cannot be used, it may be necessary to fly the aeroplane so that the target height over the microphone is less than it would be at the reference microphone station 2500 m (8202 ft) from the start of the take-off roll). In this case, the aeroplane height at the microphone location is likely to be outside the ± 20 per cent tolerance specified in 2.3.5 of Appendix 6 of the Annex. Adjustment of data to reference conditions should be performed in an approved manner.

4.1.4 Adjustment to test results

GM A6 5.2.1a
[Atmospheric Absorption Adjustment]

(1) Atmospheric Absorption

The temperature and relative humidity of the air affect the sound propagation. This correction accounts for the difference in atmospheric absorption along the sound propagation path that occurs between temperature and relative humidity under noise certification test conditions and temperature and relative humidity under reference conditions 15ºC (59°F) and 70 per cent relative humidity (see 5.2.2 of Appendix 6 of the Annex for additional atmospheric absorption correction information).

GM A6 5.2.1b
[Noise Path Adjustment]

(1) Noise Path Length

The aeroplane test limitations are that the height over the microphone shall be within ± 20 per cent of the reference height and that the lateral position shall be within ± 10° of the vertical. The noise path length correction adjusts the measured noise levels for the difference in noise path length between actual noise test conditions and reference conditions (see 5.2.2 of Appendix 6 of the Annex for additional path length correction information).

GM A6 5.2.1c
[Noise Source Adjustment]

(1) Helical Tip Mach Number

The noise generated by a propeller-driven aeroplane depends on the rotational speed of the tip of the propeller, more specifically the helical tip Mach number. Data corrections are based on the relationship between the helical tip Mach numbers determined for test and reference conditions (see 4.2.4).

Note.- The reference helical tip Mach number M_R is the one corresponding to the reference conditions above the measurement point:

GM A6 5.2.1d
[Noise Source Adjustment]

(1) Engine Power

Corrections are required to account for non-reference engine power settings that are used during noise certification tests. The procedures for determining of the engine power to be used in the calculations depend on the design characteristics of the engine-propeller combination. In most cases, this power is not published, and does not have to be determined for airworthiness purposes. It is therefore necessary to determine the power for noise certification purposes (see 4.2.4).

4.1.5 Reporting of data to the certificating authority and validity of results

GM A6 6.1.3
[Reporting of Meteorological Data]

(1) Interpretation of "each test"

For clarification, this refers to each test series (i.e. test) and each test overflight (i.e. run). The meteorological measurements should be made at the time of each test run, since each noise measurement will be corrected by use of the meteorological data.

(2) Wind Measurement

The provisions of 2.2.2c of Appendix 6 of the Annex set the limits on testing, based on a 30s average wind speed, not to exceed 19 km/h (10 kt), with a 9 km/h (5 kt) crosswind limitation. There are no additional limitations based on the surface wind.

AMC A6 6.1.5
[Reporting of Aeroplane Information]

(1) Equipment Calibrations

All equipment utilized to determine the required parameters should be calibrated, and the calibrations are to be applied before being reported to the certificating authority in the test report and before being used to make reference aeroplane corrections. The temperature at the aeroplane height should be acquired for tip Mach number correction.

(2) Mechanical Tachometers

Separate validation of the in-flight reading should be made if a mechanical tachometer is used because mechanical tachometers are subject to potential indicating errors as a result of the cable drive system

AMC A6 6.2.1
[Reference Noise Levels/Confidence Intervals]

(1) Average Noise Level Calculations

Calculation of average noise and associated confidence intervals should be accomplished as described in 2.5.

When the 90 per cent confidence limit calculated using data from six or more test flights is within ± 1.5 dB(A), then the average corrected noise level $(L_{Amax})_{avg}$ resulting from the validated data can be used to determine conformity with the Maximum Noise Levels specified in 10.4 of Chapter 10 of the Annex.

GM A6 6.2.2
[Confidence Limit Compliance]

(1) Confidence Limit Exceedance

If the 90 per cent confidence limit does not satisfy the ± 1.5 dB(A) standard, additional test data points should be obtained, increasing the number of events until the confidence limit is reduced to ±1.5 dB (A). The variability of data obtained under controlled conditions should be substantially less than ± 1.5 dB(A). If the 90 per cent confidence interval is near or above the permitted limit, the approved test procedures and/or correction procedures should be carefully reviewed.

4.2 EQUIVALENT PROCEDURES INFORMATION

The procedures described in this Chapter have been used as equivalent in stringency for propeller-driven aeroplanes with maximum certificated take-off mass not exceeding 8618 kg, as provided in Chapters 6 and 10 of the Annex.

4.2.1 Installation of add-on silencers (mufflers)

Installation of an add-on silencer (muffler) may be an effective method for reducing the noise levels of a propeller-driven aeroplane powered by a reciprocating engine. However, an add-on silencer (muffler) may also degrade the performance of the aeroplane and therefore adversely affect the aircraft's noise characteristics.

The aeroplane performance characteristics must be re-evaluated after the installation of the add-on silencer (muffler). The type design change represented by the silencer (muffler) installation can be accepted as a no-acoustical change (NAC) (see 1.2) for compliance with Chapter 6 or 10 of the Annex if the following conditions are verified to the satisfaction of the certificating authority:

a) For aircraft certificated according to Chapter 6 of the Annex the aeroplane's take-off and climb performance, as determined by the performance correction defined in 4.2.3 of Appendix 3 of the Annex, is not adversely affected; or

b) For aircraft certificated according to Chapter 10 of the Annex the aeroplane's take-off and climb performance, as determined by the reference height calculated in accordance with 10.5 of Chapter 10 of the Annex, is not adversely affected.

In either case, the add-on silencer (muffler) has no significant effect on the engine performance (i.e. power and rotational speed).

4.2.2 Guidance on use of a windscreen

For noise certification tests conducted according to Chapter 10 of the Annex the microphone shall be installed in accordance with 4.4.1 of Appendix 6, which describes how the microphone shall be mounted in an inverted position so that the microphone diaphragm is 7 mm (0.3 in) above and parallel to a circular metal plate. With this configuration, many certificating authorities have approved the use of a windscreen in order to minimise wind and turbulence induced pseudo-sound levels and to protect the microphone during the test.

A windscreen prepared and used in the following manner will cause no significant effect on the test result. The windscreen must be made from a commercially available spherical foam windscreen cut into a hemispherical shape in order to accommodate the microphone over the plate. In preparing the hemispherical windscreen the following points shall be ensured:

a) The cut surface of the windscreen must not be damaged by the cutting process; and

b) With the microphone properly inserted into the hemispherical windscreen and mounted over the ground plate, the microphone diaphragm must be at the specified distance from the plate's surface.

4.2.3 Take-off test and reference procedures

Note.- In planning a test program for noise certification according to the provisions of Chapter 10 and Appendix 6 of the Annex it is helpful to note the differences between test-day flight procedures and the standardized take-off reference profile.

The take-off reference profile is used to compute the altitude and speed of the aircraft passing over the microphone on a standard day. The requirements for this profile are contained in 10.5.2 of Chapter 10 of the Annex. They require that the first segment be computed by using airworthiness approved data, assuming take-off power is used from the brake-release point to 15 m (50 ft) above the runway. The second segment is assumed to begin precisely at the end of the first segment with the aeroplane in a climb configuration, with gear up and climb flaps, and operating at the certificated speed for best rate of climb (V_y) (see Figure 4-2).

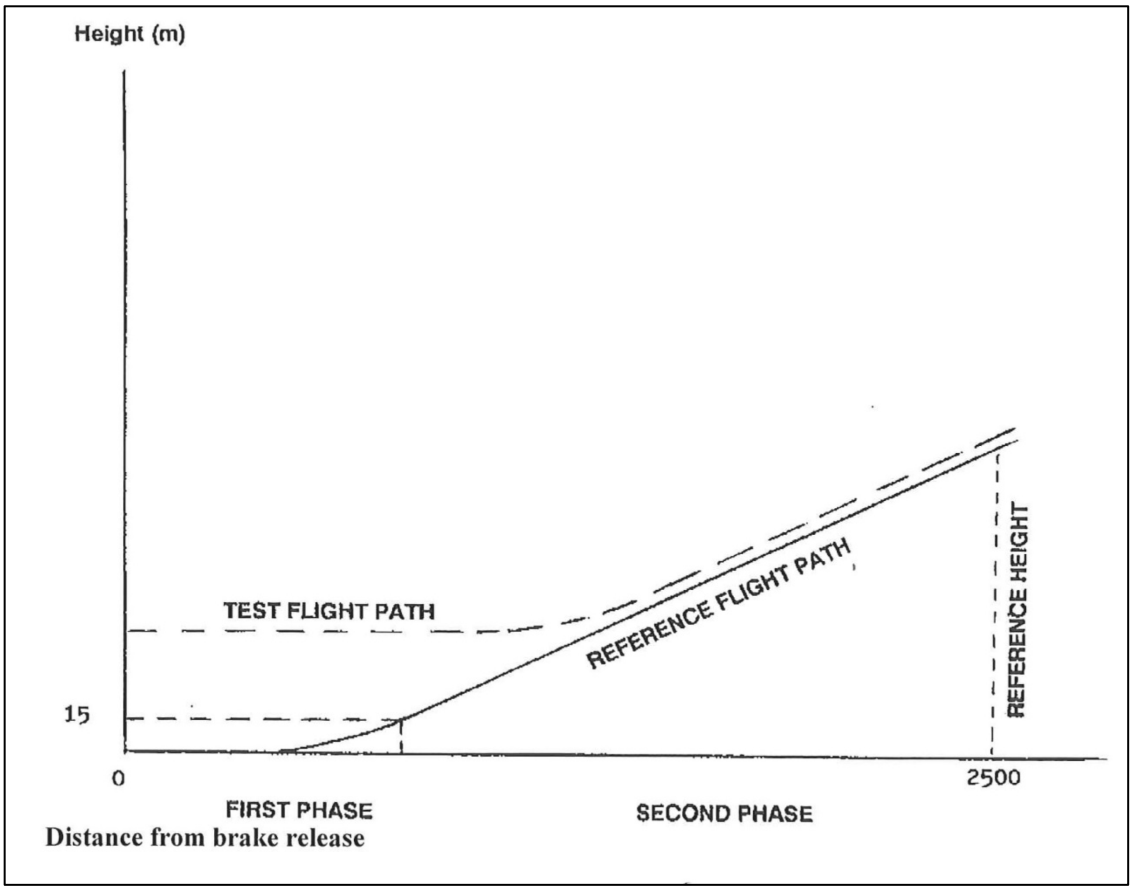


Figure 4-2 Typical Test and Reference profiles

A worked example of the calculation of reference flyover height and reference conditions for correction of source noise for aeroplanes certificated according to the Standards of Chapter 10 of the Annex is presented in 4.3.1.

The requirements for aeroplane test procedures are contained in 10.6 of Chapter 10 and 2.3 of Appendix 6 of the Annex. They basically only refer to test tolerances and approval of test plans by certificating authorities.

Figure 4-2 illustrates the difference between the test and reference procedures. Note that the actual flight test path need not include a complete take-off from a standing condition. Rather, it assumes that a flight path intercept technique is used. As with the turbojet and helicopter standards, the aeroplane should be flown to intersect the second phase (i.e. segment) climb path at the right speed and angle of climb when going over the microphone within 20 per cent of the reference height.

The take-off reference procedure defined in Chapter 10 of the Annex requires that the second phase of the procedure shall be flown at the best rate of climb speed (*V*y). The aeroplane testing procedures described in Appendix 6 of the Annex require that the flight test shall be conducted at *V*y. The reference height to which the measured noise levels are to be corrected is calculated from the climb rate corresponding to *V*y. Recent changes to the airworthiness requirements have eliminated the need to determine *V*y for small propeller driven airplanes. In this case applicants will nevertheless have to determine *V*y for the purpose of showing compliance with Chapter 10 of the Annex. If the minimum airworthiness approved climb speed is greater than *V*y then this speed shall be used and noted in the aircraft flight manual.

Applicants may alternatively show compliance with Chapter 10 at the climb speed for which the aircraft flight manual performance information is calculated provided they demonstrate, to the satisfaction of the certificating authority, that the resulting noise level is not less than would have been obtained using *V*y.

4.2.4 Source noise adjustments

Source noise adjustment data for propeller-driven light aeroplanes may be obtained by flying the test aeroplane with a range of propeller speeds for fixed pitch propellers, and a range of torque or manifold air pressure (MAP) values for variable pitch propellers.

4.2.4.1 *Fixed pitch propellers*

For aeroplanes fitted with fixed pitch propellers demonstrating compliance with Chapter 6 of the Annex source noise sensitivity curves are developed from data taken by measuring the noise level for the aeroplane flying at 300 m (984 ft) (see 6.5.2 of Chapter 6 of the Annex) at the propeller speed for maximum continuous power (N_{MCP}).

Aeroplanes demonstrating compliance with Chapter 10 of the Annex should be flown according to 2.3 of Appendix 6 of the Annex. In this way, the aircraft overflies the microphone at the reference height (H_{REF}) defined in 10.5.2 of Chapter 10 of the Annex, the best rate of climb speed (V_y) and at the propeller speed (N_{MAX}) corresponding to that defined in 10.5.2d of the “second phase” of 10.5.2 of Chapter 10 of the Annex.

For both Chapter 6 and Chapter 10 aeroplanes noise measurements are repeated at two lower propeller speeds, typically 200 rpm and 400 rpm lower than N_{MCP} or N_{MAX}. For Chapter 10 aeroplanes, these should be flown at speed V_y. The maximum A-weighted noise peak noise level (L_{Amax}) is plotted against the propeller helical tip Mach number (M_H) in order to obtain the curve from which the source noise correction may be derived.

For fixed pitch propellers, it is generally not possible to separate the two significant noise generating parameters, helical tip Mach number and the power absorbed by the propeller, by using flight tests. A sensitivity curve of Mach number versus noise level derived from flight tests of a fixed pitch propeller, either level flyovers or fixed speed climbs, will therefore include within the curve the effects not only of the Mach number but also the power. Under these circumstances, it is not appropriate to apply a separate power correction.

4.2.4.2 ***Variable pitch propellers***

For variable pitch propellers the source noise sensitivity curves are developed from data taken with the aircraft flying over a range of propeller speeds, typically three, at a fixed torque or MAP in a manner similar to that described in 4.2.4.1 where N_{MCP} or N_{MAX} would in this case be the maximum propeller speed at the maximum permitted torque or MAP. This is repeated for two lower torque or MAP values in order to establish a carpet plot of maximum A-weighted noise levels against propeller speed and torque, MAP or shaft horse power (SHP).

A plot of maximum A-weighted noise level (L_{Amax}), helical tip Mach number (M_H) and torque or MAP is developed. This plot is then used to derive the source noise adjustment (L_{Amax}) which is the difference between reference and test conditions at the noise certification power.

Generally the test and reference engine SHP can be derived from the engine manufacturer's performance curves. However, where such curves are not available, a correction should be applied to the manufacturer's published engine SHP, which is normally presented for a range of engine speeds under International Standard Atmosphere (ISA) and Sea Level conditions, in order to establish the engine power level under the test conditions of ambient temperature and air density. The correction is as follows:

a) For normally aspirated engines:

$$P_T = P_R\left[(T_R / T_T)^{1/2}\right]\left[(\sigma - 0.117)/0.883\right], \text{ and}$$

b) For turbo-charged engines:

$$P_T = P_R\left[(T_R / T_T)^{1/2}\right],$$

where:

- P_T and P_R are the test and reference engine powers;
- T_T and T_R are the test and reference ambient temperatures; and
- σ is the air density ratio.

Note.- In this context reference denotes the reference conditions for which the engine SHP is known.

4.2.5 <u>No-acoustical change guidance for derived versions of propeller-driven aeroplanes certificated according to Chapter 10</u>

After the certification in their basic configuration small propeller-driven aeroplanes are often modified, either by a TC change of the TC holder or by a STC from a supplier. These changes can be of different nature such as weight increase/decrease, engine change, power change, propeller change, installation of vortex generators, fitting of winglets or external mounted equipment (cargo boxes, floats, etc.). With regard to noise and depending on their nature some changes might have to demonstrate compliance with the applicable requirements by new flight test, others by re-evaluation of the original noise flights or by demonstrating a no-acoustical change.

The propeller and the engine are the main noise sources of small propeller-driven aeroplanes. Parameters like the diameter, the number of blades, the rpm, the pitch, the blade tip shape or the geometry could have an impact on the propeller noise signature. As for the engine, noise signature could change by modifying the rotor assembly or the exhaust.

Several Sections refer to the determination of a new reference height due to a change in performance data, here D_{15}, V_y and *RC*. New performance data are only accepted for the recalculation if they are established by a method approved by the authority.

The following sections are intended to provide guidance for applicants and certificating authorities concerning a no-acoustical change demonstration.

4.2.5.1 ***No-acoustical change guidance for aeroplanes fitted with fixed pitch propellers***

(Reserved)

Note.- This guidance is limited to variable pitch propellers only. According to ICAO Annex 16, Chapter 10, Section 10.5.2 take-off rpm shall be maintained throughout the noise test runs. During climb at the best-rate-of climb speed the fixed pitch propeller can generally not reach its maximum operating rpm value. Therefore the reference propeller speed is defined to be the average propeller rpm calculated from all valid runs. Changing the performance (e.g. due to an engine or weight change) might change the average rpm adversely. Currently the amount of change in the propeller rpm for a fixed pitch propeller cannot be estimated analytically.

4.2.5.2 ***No-acoustical change guidance for aeroplanes fitted with variable pitch propellers***

4.2.5.2.1 Engine change without power change

The engine is one of the main noise sources of the aeroplane. Changes to the engine can take many forms. They vary from small changes within one engine family, normally addressed by different characters within the engine designation to a complete re-engine. In the latter case the compliance demonstration can in general only be achieved by new noise flight tests. In the former case it is often obvious that the change has no acoustical impact and a simple statement should suffice to demonstrate that the change is not acoustically significant.

4.2.5.2.2 Power increase without changing the propeller rpm

Increasing the power output of an engine without changing the takeoff weight will increase the engine noise level at source but also improve the take-off performance. A method subjects to the approval of the certificating authority can be applied to evaluate the increase in engine noise source. This increase in engine noise source may be offset by the higher reference height. Take-off distance is shortened, the climb rate is increased and therefore the flyover height over the microphone is increased. If it can be shown that this increase in reference flyover height offsets the increase in engine source noise the change in engine power may be considered as a no-acoustical change.

A no-acoustical change is acceptable if it can be demonstrated that a minimum of six valid flights are within the "new" height window.

The effect of angle of attack change may be included in the analysis by a method approved by the authority. The method must be robust enough to account for the effects of performance and angle of attack changes on noise levels. If the analysis method shows that the noise level does not increase then the noise level of the unmodified airplane can be applied. Otherwise new testing should be required.

Note.- Paragraph 10.5.2 of Annex 16, Chapter 10 defines that the microphone has to be passed at maximum take-off power. If source noise sensitivity curves are established in accordance with the procedure laid down in the ETM, Section 4.4.2 "Source noise adjustments" the noise level can be adjusted up to the highest power covered by the sensitivity curve. In such a case the power correction determined by the sensitivity curve should be used instead of the general adjustment $\Delta_3 = K_3 \log (P_R/P_T)$.

4.2.5.2.3 Weight change

According to ICAO Annex 16, Appendix 6, Paragraph 2.3.2 the flight tests shall be initiated at the maximum take-off mass. Only increases in take-off mass up to the maximum actually flown during the original flight tests can be accepted without new flight tests. If it can be demonstrated that a further mass increase and the corresponding loss of performance do not adversely affect the noise level by more than 0.1 dB(A) the certificated noise level may be assigned to this mass without additional flight tests.

A change in the weight of the aircraft will lead to different performance characteristics. A new reference height with the new performance parameters has to be determined to demonstrate the influence on the noise level. Possible impact on the propeller speed should be taken into account.

Similar to previous section, the effect of angle of attack change may be included in the analysis by a method approved by the authority.

4.2.5.2.4 Drag change

Whilst a change in drag generally has no direct impact on the noise at source it may have an indirect effect on noise level through a change in performance.

A drag change will be in general introduced by modifications such as the fitting of cargo pods or external fuel tanks, larger tyres, floats, etc. In most cases, the change in aerodynamic noise can be shown to be negligible for small propeller-driven airplanes. However, there may be cases where the aerodynamic noise generated by the modification has to be addressed. The drag change might change the performance characteristics of the aircraft D_{15}, V_y and/or *RC* leading to a change in reference flyover height. The performance characteristics defined within the AFM are approved by the performance experts of the certificating authority. In some cases the performance experts agrees to apply the former performance parameters to the modified aircraft if the applicant can demonstrate that the performance is not worse than the one for the basic aircraft. Three different situations have to be considered:

a) The performance characteristics are better than those of the parent aircraft.

b) The performance characteristics are identical to those of the parent aircraft.

c) The performance characteristics are worse than those of the parent aircraft.

With regard to noise these three situations should be dealt with as follows:

a) In the case of situation a) independent whether the applicant decides to maintain the old performance data or to document the better performance in the AFM, a no-acoustical change can be granted and the noise level for the parent version can be applied to the modified aircraft.

b) In the case of situation b) the noise level for the parent version can be applied to the modified aircraft without further investigation.

c) In the case of situation c) in general a new flight test is required.

4.2.5.2.5 Different blade count propeller

The effect of changing the number of the propeller blades on the noise level is difficult to determine by analytical procedures. Typically the applicant is obliged to perform a new flight test. Propeller noise prediction routines are highly sophisticated requiring extensive data sets which can in general only be provided by the propeller manufacturer. The use of such propeller noise prediction routines has to be acceptable by the certifying authority to demonstrate a no-acoustical change.

4.2.5.2.6 Different blade tip shape

In general rounded tips are quieter than squared ones. The change from squared to rounded blade tips can be accepted as a no-acoustical change if the rpm and diameter remain the same.

4.3 TECHNICAL PROCEDURES INFORMATION

4.3.1 Worked example of calculation of reference flyover height and reference conditions for source noise adjustments (Chapter 10)

4.3.1.1 *Introduction*

The reference flyover height for an aeroplane certificated to Chapter 10 of the Annex, is defined at a point which is 2500 m (8202 ft) from the start-of-roll beneath a reference flight path determined according to the take-off reference procedure described in 10.5.2 of Chapter 10 of the Annex. An expression for the reference flyover height in terms of commonly approved performance data and an example of how such an expression may be worked are presented in this section. The relationship between the reference height and the conditions to which source noise corrections are to be made is also explained.

4.3.1.2 *Take-off reference procedure*

The take-off reference procedure for an aeroplane certificated to Chapter 10 is defined in 10.5.2 of Chapter 10 of the Annex under Sea Level, International Standard Atmosphere (ISA) conditions, at maximum take-off mass for which noise certification is requested. The procedure is described in two phases:

a) The first phase commences at "brakes release" and continues to the point where the aircraft reaches a height of 15 m (50 ft) above the runway. The point of interception of a vertical line passing through this point with a horizontal plane 15 m (50 ft) below is often referred to as "reference zero"; and

b) The second phase commences at the end of the first phase and assumes the aeroplane is in normal climb configuration with landing gear up and flap setting normal for "second segment" climb.

Note.- The reference "acoustic" flight path ignores the "first segment" part of the flight path, during which the aircraft accelerates to normal climb speed and, where appropriate, landing gear and flaps are retracted.

4.3.1.3 *Expression for reference height*

The reference flyover height is defined according to the take-off reference flight path at a point 2500 m (8202 ft) from the start-of-roll for an aeroplane taking off from a paved, level runway under the following conditions:

a) Sea Level atmospheric pressure of 1013.25 hPa;

b) Ambient air temperature of 15°C (59°F) (i.e. ISA);

c) Relative humidity of 70 per cent; and

d) Zero wind.

This height can be defined in terms of the approved take-off and climb performance figures for the conditions described above as follows:

$$H_R = (2500 - D_{15}) \times \tan\left[\sin^{-1}\left(\frac{RC}{V_y}\right)\right] + 15\ ,$$

where:

- D_{15} is the Sea Level, ISA, take-off distance in metres to a height of 15 m at the maximum certificated take-off mass and maximum certificated take-off power;
- RC *is* the Sea Level, ISA, best rate of climb (m/s) at the maximum certificated take-off mass and the maximum power and engine speed that can be continuously delivered by the engine(s) during this second phase; and

– V_y is the speed (m/s) for the best rate of climb.

The performance data in many flight manuals is often presented in terms of non-SI units. Typically the take-off distance, expressed in feet, is given to a height of 50 ft, the rate of climb is expressed in feet per minute (ft/min) and the airspeed in knots (kt). In such instances, the expression for reference flyover height, H_R ft, becomes:

$$H_R = (8203 - D_{50}) \times \tan\left[\sin^{-1}\left(\frac{RC}{101.4 V_y}\right)\right] + 50,$$

where:

– D_{50} is the Sea Level, ISA, take-off distance in feet to a height of 50 ft at the maximum certificated take-off mass and maximum certificated take-off power;

– *RC is* the Sea Level, ISA, best rate of climb (ft/s) at the maximum certificated take-off mass and the maximum power and engine speed that can be continuously delivered by the engine(s) during this second phase; and

– V_y is the speed (kt) for the best rate of climb.

The performance figures can normally be found in the performance section of an aircraft's flight manual or pilot's handbook. Note that for certain categories of aircraft, a safety factor may be applied to the take-off and climb performance parameters presented in the flight manual. In the case of multi-engined aircraft, it may be assumed that one engine is inoperative during part of Phase 1 and during Phase 2. For the purpose of calculating the "acoustic" reference flight path, the take-off distance and rate of climb should be determined for all engines operating by using gross (i.e. unfactored) data.

In addition, the best rate of climb speed, V_y, used in the equation for *H* is defined as the true airspeed (TAS). However in the flight manual, speed is normally presented in terms of indicated airspeed (IAS). This should be corrected to the calibrated airspeed (CAS) by applying the relevant position error and instrument corrections for the airspeed indicator. These corrections can also be found in the manual. For an ISA day at Sea Level, the TAS is then equal to the CAS.

4.3.1.4 ***Reference conditions for source noise adjustments***

Paragraphs 5.2.1c and 5.2.1d of Appendix 6 of the Annex describe how corrections for differences in source noise between test and reference conditions shall be made.

The reference helical tip Mach number and engine power are defined for the reference conditions above the measurement point (i.e. the reference atmospheric conditions at the reference height, H_R).

The reference temperature at the reference height (H_R) is calculated under ISA conditions (i.e. for an ambient Sea Level temperature of 15°C and assuming a standard temperature lapse rate of 1.98°C per 1000 ft). The reference temperature, T_R °C, can be defined as:

$$T_R = 15 - 1.98\left(\frac{H_R}{1000}\right).$$

The reference atmospheric pressure, P_R hPa, is similarly calculated at the reference height (H_R) for a standard Sea Level pressure of 1013.25 hPa, assuming a standard pressure lapse rate such that:

$$P_R = 1013.25\left[1 - \left(6.7862 \times 10^{-6} H_R\right)\right]^{5.325}.$$

4.3.1.5 ***Worked example for the calculation of reference flyover height and the associated reference atmospheric conditions***

4.3.1.5.1 For reference flyover height calculation

In Table 4-1 extracts are presented from the performance section of a flight manual for a typical light, single engined propeller-driven aeroplane.

The introduction contains a statement to the effect that the information is derived from "measured flight test data" and includes "no additional factors".

The Sea Level, ISA take-off distance in feet to a height of 50 ft at the reference conditions cited in Chapter 10 of the Annex can be read from the table of take-off distances presented for a paved runway at the maximum certificated take-off weight of 1920 lb. Thus D50 is 1370 ft.

The rate of climb (RC) at the reference conditions can similarly be read from the rate of climb (RC) table. Thus RC is 1000 ft/min.

The climb speed associated with the rate of climb figures is given as 80 kIAS. The corresponding true airspeed at the reference conditions cited in Chapter 10 of the Annex is equal to the indicated airspeed (IAS), corrected according to the airspeed calibration table at the appropriate flap setting of 0°. Thus Vy is 81 kTAS.

Entering these parameters into the equation for reference height expressed in feet (H_R ft) given in 4.3.1.3 gives:

$$H_R = (8203 + 1370) \times \tan\left[\sin^{-1}(1000/101.4 \times 81)\right] + 50,$$

and so H_R = 888 ft.

4.3.1.5.2 For calculation of reference atmospheric conditions

a) The reference temperature at the reference height, $\boldsymbol{H_R}$, is given by the equation for T_R in 4.3.1.4:

$$T_R = 15 - 1.98\left(\frac{888}{1000}\right), \text{ and so}$$

and so T_R = 13.24°C.

b) The reference pressure at the reference height is given by: the equation for P_R in 4.3.1.4:

$$P_R = 1013.25\left[1 - \left(6.7862 \times 10^{-6} \times 888\right)\right]^{5.325},$$

and so P_R = 981 *hPa.*

SECTION 5. PERFORMANCE

1. INTRODUCTION

The data processed in this section enables flight planning to be carried out for flights between airfields with various altitudes, temperatures and field lengths. The information is derived from measured flight test data using CAA-approved methods and factors to cover all the conditions shown. The data assumes average pilot skill and an aircraft engine and propeller in good condition.

No additional factors are included and it is the pilot's responsibility to apply safety factors which must not be less than those…

6. AIRSPEED CALIBRATION

0° flap	KIAS	—	60	70	80	90	100	110	120	130	180
	KCAS	—	61	71	81	91	101	111	121	131	181
15° flap	KIAS	50	60	70	80	85	—	—	—	—	—
	KCAS	51	61	71	81	86	—	—	—	—	—
35° flap	KIAS	50	60	70	80	85	—	—	—	—	—
	KCAS	50	59	69	79	84	—	—	—	—	—

TAKE-OFF DISTANCE — PAVED RUNWAY (1) — Conditions

Flaps — 15°
Weight — 1 920 lbs "
Power — Full throttle

Rotation speed — 53 KIAS
Speed at 50 ft — 65 KIAS

AIR-FIELD HEIGHT FT	ISA –20°C		ISA –10°C		ISA		ISA +10°C		ISA +20°C		ISA +30°C	
	GMD Roll	Total to 50 ft	GMD Roll	Total to 50 ft	GMD Roll	Total to 50 ft	GMD Roll	Total to 50 ft	GMD Roll	Total to 50 ft	GMD Roll	Total to 50 ft
Sea level	530	1 230	565	1 290	600	1 370	700	1 580	750	1 715	840	1 900
5 000	1 045	2 835	1 065	2 435	1 090	2 580	1 170	2 670	1 295	2 840	1 290	2 905
10 000	1 0465	3 335	1 490	3 390	1 510	3 435	1 575	3 560	1 610	3 695	1 670	3 790

RATE OF CLIMB — Conditions

Flaps UP
Weight — 1 920 lbs

Full throttle
Speed — 80 KIAS

PRESSURE ALTITUDE FT	Rate of climb Feet/Minute			
	ISA –20°C	ISA	ISA +10°C	ISA +20°C
Sea level	1 035	1 000	915	825
1 000	980	945	860	770
2 000	925	890	805	720
3 000	870	830	750	665
4 000	815	775	695	610
5 000	765	720	640	560
6 000	700	665	585	505
7 000	635	605	560	450
8 000	570	550	475	395
9 000	495	480	410	335
10 000	415	405	335	270

Table 4-1. Example of flight manual performance section

Chapter 5

GUIDELINES FOR HELICOPTERS NOT EXCEEDING 3175 kg EVALUATED UNDER APPENDIX 4 OF ICAO ANNEX 16, VOLUME I

5.1 EXPLANATORY INFORMATION

5.1.1 General

Helicopters not exceeding 3175 kg (7000 lb) can be certificated under either Chapters 8 or 11 of the Annex. Helicopters exceeding 3175 kg (7000 lb) can only be certificated under Chapter 8 of the Annex. Guidelines for helicopters certificated using Chapter 8 of the Annex are provided in Chapter 3 of this Manual.

Unlike Chapter 8 of the Annex which requires takeoff, overflight and approach tests with noise measurements being made at 3 measuring points, compliance with Chapter 11 of the Annex is based on overflight tests only, with the noise data being obtained only at one microphone located under the flight track. Flight path adjustments are simplified and the final results determined in terms of Sound Exposure Level (SEL) instead of Effective Perceived Noise Level (EPNL).

Also since the Chapter 11, Annex 16, procedure is based on overflight tests only there are no trade-off provisions between flight conditions as allowed in Chapter 8 of the Annex. However, if a helicopter not exceeding 3175 kg (7000 lb) fails to comply with the noise limit of Chapter 11 of the Annex, certification of the helicopter under the Chapter 8, Annex 16, procedures is allowed.

5.1.2 Noise certification test and measurement conditions

AMC A4 2.1
[General]

(1) Applicant's Responsibility

An applicant should prepare a noise compliance demonstration plan as described in 1.4 that specifies a proposed certification process, including equivalencies. This plan is to be submitted to the appropriate certificating authority allowing sufficient time to permit adequate review and possible revisions prior to the start of any noise certification testing.

GM A4 2.2.1
[Test Site Selection]

Section 2.1 provides a description of the technical procedures that applicants should follow in selecting a noise certification test site for helicopters not exceeding 3175 kg (7000 lbs) and evaluated under Appendix 4 of the Annex.

AMC No. 1 A4 2.2.2
[No precipitation]

(1) Effects of Moisture on Microphones

Most microphones that are used during noise certification testing are susceptible to moisture. Precipitation, including snow, drizzle and fog, or excessive humidity may induce electrical arcing of the microphone sensors, making measured noise data unacceptable. However, some pre-polarized microphones are less susceptible to electrical arcing during high-moisture conditions (consult the equipment manufacturer's specifications). Special care should be taken to ensure that any windscreens exposed to precipitation be thoroughly dry, inside and out, before use. Foam windscreens can trap water and wet foam windscreens should be avoided.

(2) <u>Microphone Internal Heaters</u>

When internal heaters are provided, microphones are less likely to be affected by moisture in wet, humid, cold, or freezing atmospheric conditions.

<u>AMC No. 2 A4 2.2.2</u>
[Atmospheric test conditions]

(1) <u>Temperature/Relative Humidity Test Window</u>

Tests are permitted over the range of temperature and relative humidity specified in 2.2.2b of Appendix 4 of the Annex and shown in Figure 5.1.

(2) <u>Testing Outside the Temperature and Relative Humidity Window</u>

If the limits of 2.2.2b of Appendix 4 of the Annex cannot be met but the tests can be conducted within the temperatures/relative humidity limits specified in 2.2.2.2b of Appendix 2 of the Annex then the applicant may alternatively elect to use the equivalent procedure defined in 5.2.2.2.

(3) <u>Meteorological Measurements</u>

Measurements of the meteorological conditions are required to be made using equipment approved by the certificating authority. The temperature, relative humidity and wind measurements are required to be made in the vicinity of the noise measurement point at a height between 1.2 m (4 ft) and 10 m (33 ft). This allows the use of hand-held equipment, but does not preclude the use of more complex measuring systems. Temperature and relative humidity may be measured by a hand-held psychrometer. This device measures the wet and dry bulb temperatures from which the relative humidity is obtained. Similarly wind measurements may be made using a hand-held device if its specifications comply with the provisions of 2.2.2.1 of Appendix 2 of the Annex.

If an applicant can show that measurements taken are representative of those at the test site, meteorological measurements can, subject to approval by the certificating authority, be obtained from a fixed meteorological station, such as found at a nearby airport. Such facilities normally have to be within 2000 m (6560 ft) of the test site and approval will normally require the applicant to show that the measurement systems have been calibrated within 90 days prior to the tests and, equally important, document that the measurement systems comply with the requirements of 2.2.2.1 of Appendix 2 of the Annex and that measurements are representative of those at the test site.

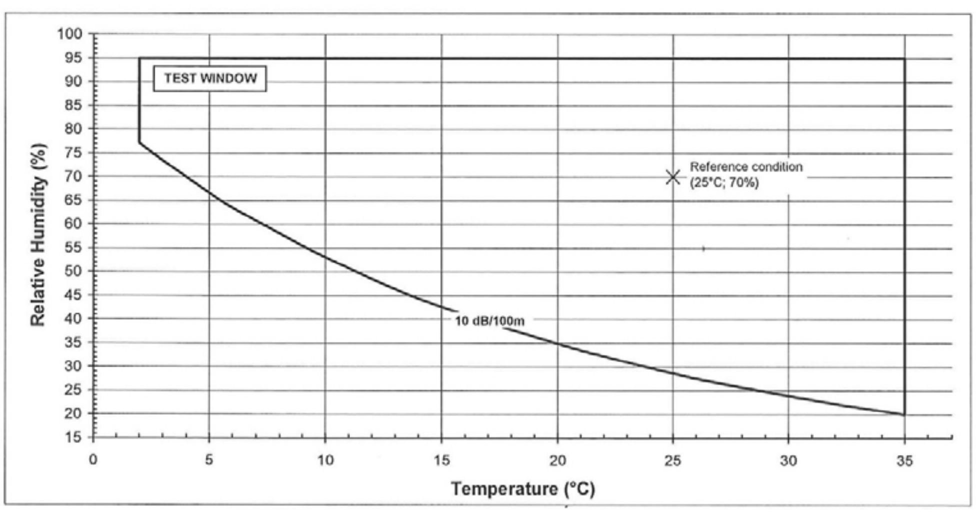


Figure 5-1 Appendix 4 temperature /relative humidity test window

Although use of airport measurement systems are allowed, an applicant may find merit in using an approved portable system for ease of obtaining measurements and confirming that the temperature, relative humidity, and wind speeds are within the required values. This will be particularly important when any of the values, and in particular the wind speed, are near any of the limits. Applicants should also note that in order to determine the crosswind component to the required accuracy, the wind direction as well as wind speed is required. Experience suggests that some small airfield/airport direction indicators have a slow response to rapid changes in wind direction and are not well suited to such measurements.

(4) Temperature and Relative Humidity

Measurements of temperature and relative humidity should be made at intervals of not more than one hour to ensure that the test conditions remain in the required limits. It is advisable to make measurements for each flight in case it is required at a later time to verify the test conditions.

Section 5.2.2.2 provides an equivalent procedure to the specifications for temperature and humidity measurement given in 2.2.2b of Appendix 4 of the Annex.

AMC No. 3 A4 2.2.2
[Anomalous meteorological conditions]

(1) OAT Differential

The presence of anomalous meteorological_conditions can be reasonably determined by monitoring the outside air temperature (OAT) using the helicopter onboard temperature gauge. Anomalous conditions which could impact the measured levels can be expected to exist when the OAT at 150 m (492 ft) is higher than the temperature measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above the ground by more than 2°C (3.6ºF). This check should be made in level flight at a height of 150 m (492 ft) within 30 minutes of each noise measurement.

AMC No. 4 A4 2.2.2
[Windspeed]

(1) Windspeed Limitations

Wind speed measurement points and limits are given in 2.2.2c of Appendix 4 of the Annex. Wind speed measurement system specifications are given in 2.2.2.1 of Appendix 2 of the Annex. Measurements should be taken frequently and, if near the limit, at least prior to each flight to confirm that the requirements are met. Particular attention should be given to the crosswind component since this can often be the limiting factor during testing. If feasible, the reference flight path direction can be changed to reduce the impact of this requirement. These wind speeds should be recorded and included in the report of the noise certification program. Wind limits are intended to minimize adverse effects of wind on helicopter noise generation and sound propagation.

AMC No. 5 A4 2.2.2
[Anomalous wind conditions]

(1) Identification of Anomalous Winds

Anomalous winds are difficult to quantify but, providing the helicopter can be easily flown within the flight path and airspeed limits defined in the Annex, there is no excessive side slip or yawing of the helicopter and no indication of rough air, then the flights can be considered acceptable. In the case where wind effects are anticipated to be a likely problem an agreement between the applicant and the certificating authority or designated observer should be reached prior to testing to determine the acceptability criteria. Normally such issues only arise with gusty wind conditions near the 10 kt wind speed limit, high crosswind conditions or the presence of strong thermals.

AMC A4 2.3.1
[Aircraft position measurement]

(1) Aircraft Position Measurement

Several methods have been approved for measurement of aircraft position that are independent of normal flight instrumentation. Examples of previously accepted aircraft position measurement systems such as radar tracking systems, theodolite triangulation and photographic scaling are described in 2.2.1, 2.2.2, 2.2.3 and 2.2.4. Guidance for obtaining approval of differential global positioning systems (DGPS) is provided in 2.2.5. Photo-scaling methods based on video camera systems have also been approved.

Certificating authorities have generally approved systems when applicants are able to demonstrate an acceptable level of accuracy for determining the aircraft position relative to the noise measurement points. Adequate system documentation is also required.

GM A4 2.4
[Flight test conditions]

(1) Overflight Height

A reference overflight height of 150 ± 15 m (492 ± 50 ft) above the ground at the noise measurement point is specified as indicated in Figure 5-3. The measured noise data must be adjusted for the effects of spherical spreading between the helicopter test flight path and the reference flight path, and between reference airspeed and adjusted reference airspeed as specified in 5.2.2 of Appendix 4 of the Annex.

(2) Flight Path Measurement

The helicopter flight path is also required to be within ± 10° from the vertical above the noise measurement point (see Figure 5-3). This requirement, along with the height test window, means that the helicopter has to fly through a height/off-track test window located directly above the noise measurement point. There is no requirement to determine the magnitude of the off-track distance, but it is necessary to show that the helicopter is within the required height and angular limits. The applicant may, therefore, find merit in recording the off-track values for subsequent confirmation of compliance.

(3) Flight Track: Markings

The helicopter has to fly on a straight path and be within ± 10° of the vertical overhead the noise measurement point as shown in Figure 5-2. In order for this to be successfully accomplished the applicant should consider marking on the ground, in a manner that can be readily seen from the helicopter, the intended track and associated lateral limits. Brightly coloured or day-glow markers or lights to mark the flight track are advisable. These markings will be very important in the case of a small helicopter where the on-board equipment may be the minimum required to comply with the airworthiness certification.

(4) Number of Test Runs

A minimum of six overflights, with an equal number of flights with head wind and tail wind components over the noise measurement point, are required. These test runs should be conducted in pairs, since the aim is to minimize the influence of wind speed direction on the measured SEL. The tests in each pair should be conducted immediately one after another in order that the meteorological conditions are as similar as possible for the two test runs. It should be possible to determine immediately after each test run if it meets the necessary requirements and thus relatively easy to establish when three pairs of valid test runs have been made. The applicant would also be advised to conduct one or two additional pairs of test runs to ensure that after all the test parameters have been examined a minimum of three valid pairs of test run results are available. If additional valid pair(s) of test runs are obtained these will be required to be included in the analysis to determine the arithmetic average SEL level.

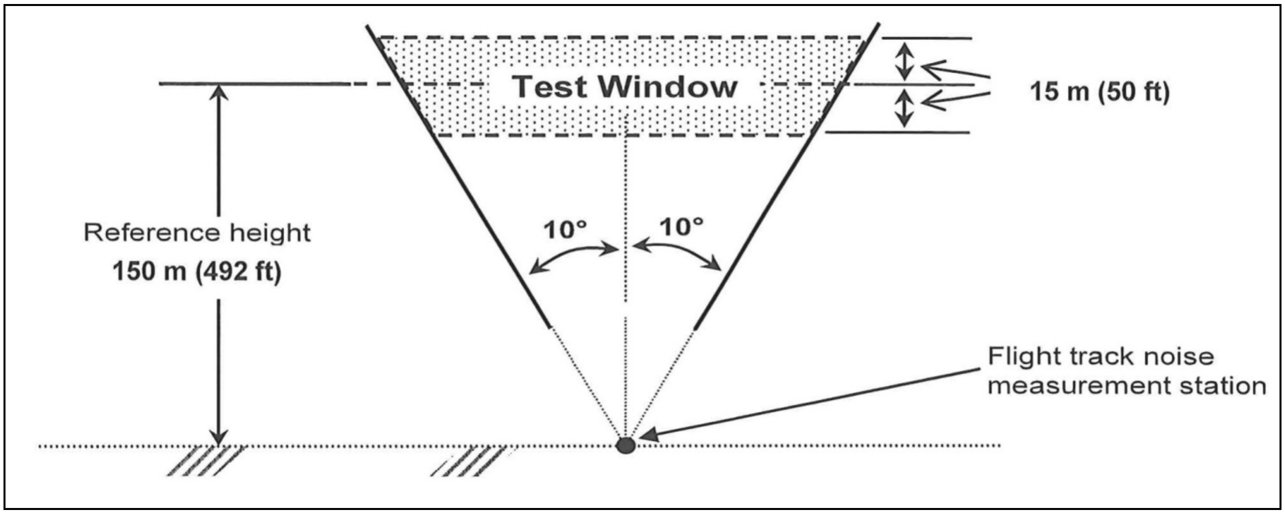


Figure 5-2 Flight boundaries for overflight test condition

(5) Landing Gear Position

If the helicopter has a retractable landing gear the landing gear position for noise tests needs to be that used for the cruise configuration.

AMC A4 2.4
[Flight test conditions]

(1) Test Period

The test conditions have to be maintained, or held constant, over an adequate distance (time period) to encompass the 10 dB-down period. The maximum A-weighted sound pressure level, dB(A) or L_{Amax}, will normally occur when the helicopter is at, or just prior to, the position directly above the noise measuring point. Pre-test flights should be conducted to determine the 10-down period and ensure this period is adequately captured by the noise measurement system. It is advisable that the helicopter flight test conditions are stabilized well in advance of the initial 10 dB-down point and maintained until well after the second 10 dB-down point to ensure a valid noise measurement is obtained.

(2) Maximum Normal Operating Rotor Speed

In order that the noise levels are representative of normal operation the rotor speed used must be the maximum normal value associated with flyover at the reference conditions. Also, since on most helicopters small changes in rotor speed occur during a stabilized flight, a ± 1 per cent rpm variation is allowed.

(3) Test Mass

Fuel, together with the mass of the pilot, flight observer(s), and ballast are normally used to set the mass of the test helicopter within the required test range of +5 per cent/-10 per cent of the maximum take-off mass. Fuel burn (i.e. decrease in fuel mass) should be documented to determine the actual test value. Care must be taken regarding the location of ballast to ensure it does not have any adverse impact on the applicable center of gravity (c.g.) limits.

Unlike in Chapter 8, there is no requirement to conduct any test run above the maximum take-off mass. Note that variation of the overflight noise levels within the allowable mass limits is small and for this reason no adjustments for difference in test masses are required. The helicopter mass, or the quantity of fuel from which the mass of the helicopter can be calculated, should be recorded for each flight.

Note.- Conducting the tests as near as possible to the upper mass limit of +5 per cent can also be useful in supporting noise certification of future increases in maximum gross mass of the helicopter by minimizing the liklihood of having to conduct new tests.

(4) Background Noise

Some initial pre-test overflights should be performed to confirm helicopter noise levels exceed background noise by 15 dB(A) as specified in 4.4.4 of Appendix 4 of the Annex. Certificating authorities have generally accepted that the requirement has been met if the maximum helicopter noise level exceeds background noise levels by 15 dB(A). If this requirement cannot be met when the overflight test is conducted at 150 m (492 ft), a lower overflight height approved by the certificating authority may be used. This normally will only be required in the case of lightweight/small helicopters or those that generate extremely low noise levels

Variations in measured noise levels from flight-to-flight of up to ± 1.5 dB(A) may typically occur. The applicant should therefore ensure that the difference between background noise and helicopter noise levels is adequate for the quietest overflight noise measurements anticipated. Such information may also be useful for adjusting the sensitivity of the noise measurement system. The level of background noise may be influenced by the location of the test site

GM A4 2.4.2
[Flight test conditions]

(1) Adjusted Reference Airspeed

The overflight adjusted reference airspeed (V_{AR}) is defined as the value at the test temperature that gives the same advancing main rotor blade tip Mach number (M_{AT}) as associated with the reference temperature of 25°C (77ºF). On most helicopters the controlling noise source is dependent on the advancing blade tip Mach number. The advancing blade tip Mach number is dependent on the temperature and thus the sound level varies with temperature. To avoid the need to make a source noise correction, as would be required for the overflight tests under Appendix 2 of the Annex unless an equivalent procedure is used, tests to meet the requirements of Appendix 4 of the Annex are required to be conducted at an adjusted reference airspeed, V_{AR}, which gives the same advancing blade tip Mach number at the time of the test as would occur if the test were conducted under the reference conditions. The speed of sound increases with absolute temperature so that tests conducted in temperatures below the reference value of 25°C (77ºF) at the reference overflight height will result in higher advancing blade tip Mach number, and a reduction in test airspeed will be required to obtain the reference advancing blade tip Mach number. Similarly when the air temperature at overflight reference height is higher than 25°C (77ºF), the overflight test speed must be increased. This requires knowledge of the OAT measured on-board the aircraft at the time of the test. The applicant should note that it is essential to test at the required airspeed value since there is no provision for the adjustment of data obtained at the wrong Mach number.

AMC No. 1 A4 2.4.2
[Flight Test Conditions]

(1) Test Speed for Light Helicopters

For the purposes of compliance with Chapter 11 of the Annex the helicopter should be flown at test speed (V_{AR}) which will produce the same advancing blade Mach number (M_R) as the reference speed in reference conditions given in 11.5.1.4 and 11.5.2.1b of Chapter 11 of the Annex.

The reference advancing blade Mach number (M_R) is defined as the ratio of the arithmetic sum of the main rotor blade tip rotational speed (V_{TIP}) and the helicopter true airspeed (V_{REF}) divided by the speed of sound (c) at 25°C (346.1 m/s) such that:

$$M_R = \frac{V_{REF} + V_{TIP}}{c}.$$

The test airspeed (V_{AR}) is calculated from:

$$V_{AR} = c_T \left(\frac{V_{REF} + V_{TIP}}{c} \right) - V_{TIP} ,$$

where c_T is the speed of sound obtained from the on-board measurements of outside air temperature.

Since the ground speed obtained from the overflight tests will differ from that for reference conditions, an adjustment Δ_2 of the form:

$\Delta_2 = 10 \log (V_{AR} / V_{REF}),$

will need to be applied. Δ_2 is the increment in decibels that must be added to the measured sound exposure level (*SEL*).

There are two additional requirements for light helicopter test speed. Firstly, the airspeed during the 10 dB-down period should be close (i.e. within ± 5 km/h (3 ± kt)) to the adjusted reference speed (see 11.6.7 of Chapter 11 and 2.4 2 of Appendix 4 of the Annex).

The second speed requirement states that the level overflights shall be made in equal numbers with a headwind component and tailwind component (see 11.6.4 of Chapter 11 of the Annex). For practical reasons, if the absolute wind speed component in the direction of flight, as measured at a height between 1.2 m (4 ft) and 10 m (33 ft) above ground (see 2.2.2c of Appendix 4 of the Annex), is less than 9 km/h (5 kt), then the effect of wind can be considered to be negligible. In this case, the measured overflight may be used to satisfy a test run in either the headwind or tailwind direction if the overflights are conducted in pairs. Each pair should consist of two overflights performed one after the other in opposite directions over the reference flight track.

Any changes in rotor speed, which may occur with the flight airspeed, will also need to be taken into account in the above calculations to determine the adjusted reference airspeed. If this is likely to occur then this topic should be reviewed with the certificating authority to determine if any additional adjustments to the flight test speed are required. Normally this is not a concern, since the rotor speed will be independent of flight speed.

The applicant should also note that the calculated adjusted reference airspeed (V_{AR}) is the adjusted true airspeed (TAS). Additional information will be required to determine the indicated airspeed (IAS) for use by the pilot. This will normally be based on calibration charts or adjustments for the airspeed measurement system showing the IAS/TAS relationship.

AMC No. 2 A4 2.4.2
[Flight test conditions]

(1) Rotor Speed

The rotor speed can be varied on some helicopters, and on others variations in the rotor speed can occur with flight speed. In order that the noise levels are representative of normal operation, the rotor speed used must be the maximum normal value associated with overflight at the reference conditions.

Note.- It is not the intent to require noise measurements at any value but the maximum used during normal operations, and thus testing at the maximum tolerance rotor speed is not required.

On some helicopters two distinct rotor speed values are available. If both can be used for normal operations then the noise certification has to be conducted at the higher rotor speed. If the higher of the two speeds is restricted to special operations, or if the helicopter is configured so that it cannot be used at the reference conditions and/or during lower altitude flight, then subject to approval by the certificating authority testing at the lower rotor speed may be allowed.

On some helicopters it may be possible for the rotor speed to be changed by pilot action. In these cases noise certification will require the highest rotor speed specified in the Rotorcraft Flight Manual for the overflight flight condition at the maximum take-off mass to be used.

For most turbine engine powered helicopters the rotor speed is automatically linked by the engine control/governor system to the flight condition. If this results in a different rotor speed at the adjusted reference airspeed to that associated with the reference airspeed, then additional adjustments to ensure the correct advancing blade tip Mach number is used for the tests may be required. If this situation is likely to occur, certificating authority approval on the rotor speed and/or adjusted reference airspeed to be used should be obtained.

On some recently designed helicopters the use of lower rotor speeds have been certificated for operations at low altitudes and/or in cruise flight. Since these lower rotor speeds are defined in the Rotorcraft Flight Manual and if higher rotor speed values cannot be used at the reference conditions, except possibly in an emergency, noise certification is conducted at the certificated lower rotor speed, subject to approval by the certificating authority. If, however, the helicopter simply incorporates a two speed or multi-speed system, and either can be selected by the pilot, then the highest value is required to be used for noise certification.

5.1.3 Noise unit definition

GM 3.1
[Units]

The noise levels are to be determined in terms of the Sound Exposure Level (SEL) metric. The Sound Exposure Level is the time integrated A-weighted sound level over the 10 dB-down period. This metric takes into account both the duration and the level of the sound.

5.1.4 Measurement of helicopter noise received on the ground

AMC A4 4.3
[Noise measurement system]

(1) System and Calibration Requirements

The noise measurement system and system calibration requirements are specified in 4.1 through 4.3 of Appendix 4 of the Annex for compliance with Chapter 11 of the Annex. The noise demonstration compliance test plan must include a description of the system to be used for the noise measurement. The certificating authority must approve the measurement system and calibration procedures in order to ensure that accurate measurements and results are obtained.

AMC A4 4.4
[Noise measurement procedures]

(1) In-field Calibration

Procedures for calibration of the noise measurement system are specified in section 4 of Appendix 4 of the Annex. A sound calibrator is normally used for in-field calibrations. This provides a sine wave at a known sound pressure level and the signal is introduced into the system by placing the calibrator over the microphone. The level of the calibration signal should be reported. If a recorder is used, the calibration signals need to be recorded at the beginning and end of each series of tests and/or each tape used. If there is delay between the individual flights in the test series, calibrations should be made when the flight tests stop and again when restarted. If the tests extend over a long period calibrations are also required at intervals approved by the certificating authority. The sound calibrator can be used to check that the measurement system is operating correctly. Such checks should be made at frequent intervals during the recording period.

(2) Adjusted calibration level

The calibration adjustments, including those for environmental effects (e.g. ambient temperature and pressure) on the sound calibrator output levels, must be taken into account to determine the sound pressure level.

(3) Sound Level Integration Period

The A-weighted sound pressure level must be integrated over the 10 dB-down period. When using an integrating sound level meter where the start and stop times are selected manually, the actual test integration period should be slightly longer than the true 10 dB-down period. This will not have any significant impact on the SEL value providing the integration period is only a few seconds longer since the noise levels will be more than 10 dB(A) below the maximum sound level value.

5.1.5 Adjustment of test results

AMC A4 5.0
[Data adjustments]

(1) Height Adjustment

In order to account for the differences between the test heights (H) and reference height of 150 m (492 ft) which influence both the spherical spreading of the noise and the duration of the 10 dB-down period, the Δ_1 adjustment is applied.

(2) Airspeed Adjustment

In order to account for the differences between the adjusted reference airspeed (V_{AR}) and reference airspeed (V_{REF}) which influence the duration of the 10 dB-down period, the Δ_2 adjustment is applied. Variations in the ground speed, and hence duration, as a result of wind at the test height also occur, but since test runs are to be made with equal numbers with headwinds and tailwinds (see 11.6.4 of Chapter 11 of the Annex), this effectively cancels out this effect and no additional adjustments for duration are required.

5.1.6 Reporting of data to the certificating authority

AMC A4 6.0
[Data Reporting]

(1) Reporting Requirements

Noise certification data reporting requirements are detailed in Section 6.0 of Appendix 4 of the Annex. Compliance with stabilized test conditions, including test airspeed, average rotor speed and overflight height, should be reported for the 10 dB down period. If an acoustic data recording is made, information about the recorder including frequency bandwidth and sample rate and operating mode should be recorded.

(2) Lateral Position Flight Track Data

There is no requirement to determine the lateral off-track position directly above the noise measurement point, since it is only necessary to show that it is within the requirements defined in 11.6.8 of Chapter 11 of the Annex. Even so, an applicant may find merit in determining and reporting the lateral off-track distance as a way, with the height information that is required, to show compliance.

5.2 EQUIVALENT PROCEDURES INFORMATION

5.2.1 General

The objective of a noise certification demonstration test is to acquire data for establishing an accurate and reliable definition of a helicopter's noise characteristics. In addition, the Annex establishes a range of test conditions and procedures for adjusting measured data to reference conditions.

5.2.2 Procedures for the determination of changes in noise levels

Noise level changes determined by comparison of flight test data for different helicopter model series have been used to establish certification noise levels of modified or newly derived versions by reference to the noise levels of the baseline or "flight datum" helicopter model. These noise changes are added to or subtracted from the noise levels obtained from individual flights of the "flight datum" helicopter model. The confidence intervals of the new data are statistically combined with the "flight datum" data to develop overall confidence intervals (see 2.5).

5.2.2.1 *Modifications or upgrades involving aerodynamic drag changes*

The use of drag devices, such as drag plates mounted beneath or on the sides of the "flight datum" helicopter, has proven to be effective in the noise certification of modifications or upgrades involving aerodynamic drag changes. External modifications of this type are made by manufacturers and aircraft "modifiers". Considerable cost savings are realized by not having to perform noise testing of numerous individual modifications to the same model series.

Based on these findings, it is considered acceptable to use the following as an equivalent procedure:

a) For helicopters to be certificated under Chapter 11 of the Annex a drag device is used that produces the aerodynamic drag calculated for the highest drag modification or combination of modifications;

b) With the drag-producing device installed, an overflight test is performed by using the appropriate noise certification reference and test procedures;

c) A relationship of noise level versus change in aerodynamic drag or airspeed is developed by using noise data, adjusted as specified in Appendix 4 of the Annex, of the "flight datum" helicopter and of the "high drag" configuration;

d) The actual airspeed of the modification to be certificated is determined from performance flight testing of the baseline helicopter with the modification installed; and

e) Using the measured airspeed of the modification, certification noise levels are determined by interpolation of the relationship developed in item c.

5.2.2.2 *Testing of light helicopters outside Chapter 11 temperature and humidity limits*

With the approval of the certificating authority, it may be possible to conduct testing of light helicopters in compliance with the temperature and relative humidity test limits specified in 2.2.2.2b and 2.2.2.2c of Appendix 2 of the Annex (see Figure 5-3) instead of the limits specified in 2.2.2b of Appendix 4 of the Annex. Temperature and relative humidity measurements shall be made between 1.2 m (4 ft) and 10 m (33 ft) above ground as specified in 2.2.2b of Appendix 4 of the Annex and within 30 minutes of each noise measurement as required by 2.2.2.3 of Appendix 2 of the Annex. In such circumstances, it will be necessary to conduct a one-third octave band analysis of a noise recording of each overflight. The measured value of sound exposure level (SEL) shall be adjusted from the test values of temperature and relative humidity to the reference conditions defined in 11.5.1.4 of Chapter 11 of the Annex. The adjustment procedure shall be similar to that defined in 8.3.1 of Appendix 2 of the Annex with the propagation distances QK and Q_rK_r, respectively replaced by H, the height of the test helicopter when it passes over the noise measurement point, and the reference height, 150 m (492 ft).

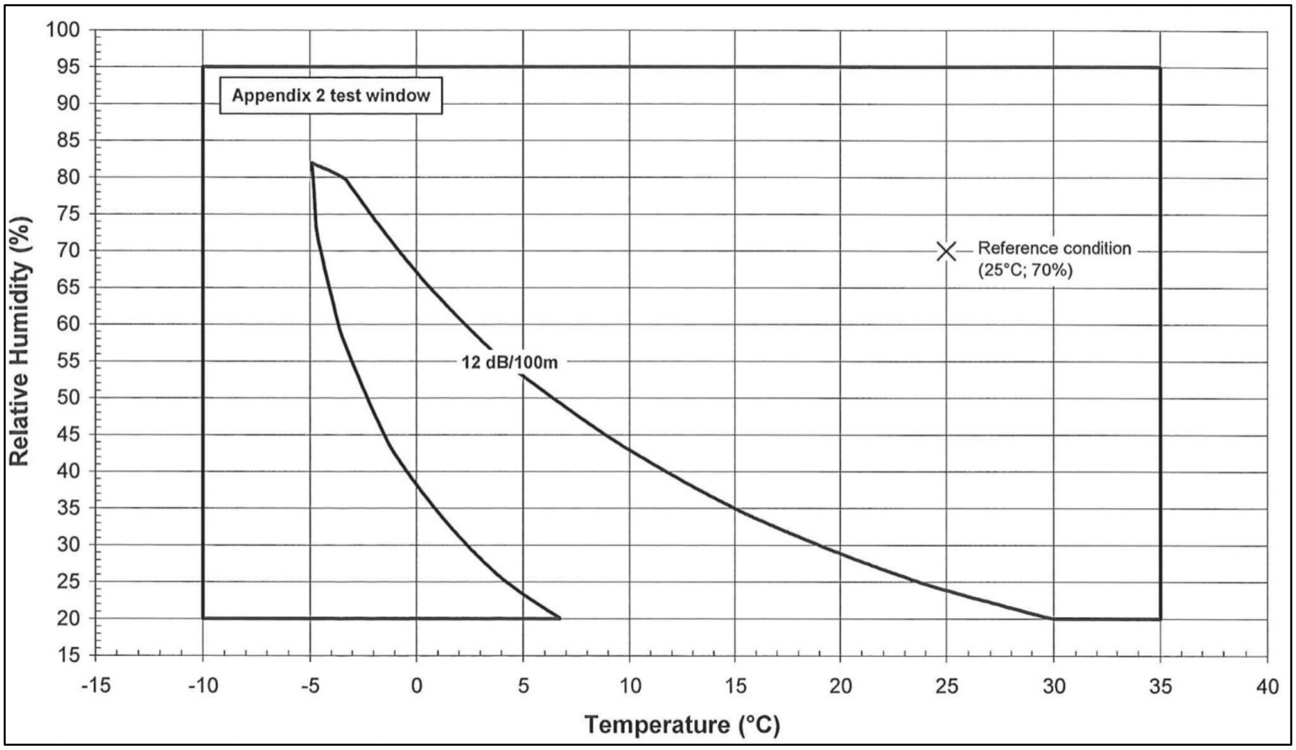


Figure 5-3 Optional Appendix 2 temperature/relative humidity test window

Chapter 6

GUIDELINES FOR TILT-ROTOR AIRCRAFT EVALUATED IN ACCORDANCE WITH ATTACHMENT F OF ICAO ANNEX 16, VOLUME I

6.1 EXPLANATORY INFORMATION

6.1.1 Background

GM ATT F 1
[Applicability]

(1) Intent of Attachment F Guidelines

The guidelines for the noise certification of tilt-rotor aircraft presented in Attachment F of the Annex have been developed by the CAEP Tilt-Rotor Task Group specifically for the noise certification of the Bell/Agusta BA609, the first example of a civil tilt-rotor aircraft. It is also intended that these guidelines be used as the basis for noise certification of subsequent tilt-rotor aircraft. The explanatory material in this Chapter is intended to give an insight as to how the guidelines have been developed, particularly with regard to their application to the Bell/Agusta BA609. It is hoped that the information may serve as a useful guide to the development of the guidelines to be used for other tilt-rotor aircraft and the possible eventual adoption of these guidelines as a Standard in the Annex.

(2) Scope of Attachment F Guidelines

It is considered that at this moment there is not enough experience with tilt-rotor aircraft to justify adoption of firm Standards. Therefore the guidance material has been developed in the form of Attachment F of the Annex much like the guidelines for noise certification of propeller-driven STOL aeroplanes that are in Attachment B of the Annex. It was deemed desirable to give the same level of detail as is found in comparable chapters of the Annex, including information on date of applicability, to promote a uniform application of the guidelines.

After careful deliberations, it has been concluded that the current Standards of Chapter 8 of the Annex were a good basis for the guidelines in Attachment F and that the differences between the guidelines and Chapter 8 should be minimized.

- The noise from tilt-rotors will be most prominent during departure and approach. In these situations tilt-rotors will normally operate in or near the "helicopter mode".
- In the development of the guidelines, the noise of the Bell XV-15 tilt-rotor aircraft (a prototype of the Bell/Agusta BA609) has been observed. It was concluded that the character of the noise of this aircraft was much like that of a normal helicopter.
- In horizontal overflight, the "helicopter mode" will normally be the noisiest configuration.
- The proposed guidelines are confined to tilt-rotors that can only take off vertically, excluding those with STOL characteristics. They will operate much like normal helicopters, with relatively steep take-off and approach paths.
- The level of available noise abatement technology for tilt-rotors is considered to be the same as for helicopters.
- Tilt-rotor operations will often mix with helicopter operations from the same heliport. Therefore there will be a desire to compare the noise from tilt-rotors and helicopters.

(3) Transition Phase Noise Test Point Evaluation

One item of strong interest is the transition from one nacelle angle to the other which may be associated with particular noise generation mechanisms. For example, when one considers the tilt-rotor transition from aeroplane mode to helicopter mode while decelerating, there is a phase in which the component of the speed vector that is perpendicular to the rotor changes from "top to bottom" to "bottom to top". It would be conceivable that sometime during the transition phase, blade vortices would be ingested or another non-stationary effect would create additional noise.

A number of overflights of the Bell XV-15 were listened to, one of which was especially set up to study the noise during transition. In this run, the tilt-rotor (Bell XV-15) passed overhead at 150 m (492 ft) while transitioning from aeroplane to helicopter mode. No special phenomena were heard during this flight. In addition, during the other runs, in which there were demonstrations of hover, hover turns, sideward flight, take-off, level overflights at various speeds/nacelle angles combinations and approaches at 6° and 9°, no particularities were heard, other than normal Blade Vortex Interaction noise during both the 6° and 9° approaches. During the procedures to set the aircraft up for the various runs, several transitions were made from helicopter to aeroplane mode and back, which were listened to from different positions relative to the aircraft. No particular noise was heard.

Based on this experience and the arguments stated as follows, it has been decided not to attempt to define a special test point aimed at catching transition noise of tilt-rotors.

The arguments for this are:

– Experienced observers from industry claim they never noticed any particular noise phenomena associated with the transitional phase. This was backed up by the specific observations of the Bell XV15 referred to above;

– The conversion rate is relatively slow, which means that during the whole conversion process, the flow field also changes very slowly;

– If there would be a transitional noise, it would probably be related to some form of Blade Vortex Interaction. This phenomenon is covered under the approach procedure and it might be hard to justify adding a measurement point to get some additional information;

– Defining a reproducible and practicable procedure to catch the transition noise which nobody has ever noticed is virtually impossible; and

– If in the future there is a design that has clear transitional noise characteristics, the effect could be studied and, if deemed necessary, an amendment to the guidelines could be proposed.

6.1.2 General information

GM ATT F 6
[Terms Used in Tilt-Rotor Noise Certification Procedures]

Aeroplane mode. The term "aeroplane mode" is used when the rotors are orientated with their axis of rotation substantially horizontal (i.e. engine nacelle angle near 0° on the "down stops". See GM ATT F Section 6c).

Helicopter mode. The term "helicopter mode" is used when the rotors are orientated with their axis of rotation substantially vertical (i.e. nacelle angle around 90°). In the guidelines in Attachment F of the Annex the condition is referred to as the "VTOL/Conversion mode", which is the term used in the Airworthiness Standards in development for the Bell/Agusta BA609. VTOL stands for Vertical Take-Off and Landing.

Nacelle angle. The "nacelle angle" is defined as the angle between the rotor shaft centreline and the longitudinal axis of the aircraft fuselage. The nacelle is normally perpendicular to the plane of rotation of the rotor.

Gates. In the design of the Bell/Agusta BA609, there are a number of preferred nacelle angle positions called "gates". These are default positions that will normally be used for normal operation of the aircraft. The nacelle angle is controlled by a self-centring switch. When the nacelle angle is 0° (i.e. aeroplane mode) and the pilot hits the switch upwards, the nacelles will automatically turn to a position of approximately 60°, where it will stop. Hitting the switch once more will make the nacelle turn to a position of approximately 75°. Above 75° the nacelle angle can be set to any angle up to approximately 95° by holding the switch either up, or down to go back.

The "gate" concept is expected to be typical for all future tilt-rotors, although the number and position of the gates may vary. The gates play an important role in the airworthiness requirements, where they are defined as "authorized fixed operation points in the VTOL/conversion mode". When the aircraft is flying in the aeroplane mode, the nacelle angle will be in line with the longitudinal axis of the aircraft. In this case the angle is fixed by using the so-called "down stop"

Rotor speed. The design of the Bell/Agusta BA609 and most likely future designs of tilt-rotors will have at least two possible rotor speeds: one rotor speed for the helicopter mode and another, lower, rotor speed for the aeroplane cruising mode. The lower rotor speed can only be used when the nacelles are on the down stop. Before leaving the down stop, the rotor speed must be set to the higher value for the tilt-rotor to be able to hover.

6.1.3 Information on specific Attachment F texts

GM ATT F Note 1
[Definition]

(1) Definition

The proposed definition was proposed by the International Coordinating Council of Aerospace Industries Association (ICCAIA). It focuses on the fundamental difference between tilt-rotors and other aircraft.

GM ATT F Notes 1 and 2, and Section 1
[Applicability]

(1) Applicability

An applicability section has been added to promote uniform application of the guidelines. The reference to derived versions means that no measurements are required on aircraft that are quieter than their parent aircraft due to the definition of derived versions in the Annex. The date chosen is the date when this section of the guidelines was discussed.

GM ATT F Section 2
[Noise evaluation measure]

(1) Noise Evaluation Measure

In view of the commonality with helicopters, the same units used in Chapter 8 of the Annex are proposed. It is proposed that no new appendix for tilt-rotors be created, since the current Appendix 2 of the Annex is considered to be appropriate. For land-use planning purposes, it is proposed that additional data be made available. Which data should be provided is left to be determined between the authority and the applicant, since the needs of different authorities in this respect may differ.

At this moment, the intention of this section of the guidelines is to only require data that can be gathered through additional analysis of the data that have already been measured for certification purposes. It is hoped that the Society of Automotive Engineers (SAE) will investigate further the data requirements for land-use planning. Since the information needed for land-use planning can be of such detail that it is commercially sensitive, it is not the intent to make such information available to the public.

GM ATT F Section 3
[Reference noise measurement points]

(1) Reference Noise Measurement Points

In view of the desired commonality with helicopters, the same reference noise measurement points used for Chapter 8 of the Annex are proposed.

GM ATT F Sections 4 and 5
[Maximum noise levels and trade-offs]

(1) Maximum Noise Levels and Trade-Offs

In view of the desired commonality with helicopters, it is considered that the current limits of 8.4.1 of Chapter 8 of the Annex and the trade-offs of 8.5 of Chapter 8 of the Annex serve as a good starting point for use in the guidelines. In the helicopter mode, both the lift technology and operating environment are similar to those of a helicopter. If the technology requires higher limits or makes possible lower limits, this should be considered by the individual authority when using the guidelines in a particular case. For the overflight case, there is only a limit specified for the helicopter mode, since this is normally the noisiest configuration and also the configuration most likely to be used when flying the circuit pattern.

GM ATT F Section 6
[Noise Certification reference procedures]

(1) General

The capability to change the nacelle angle and the two different, possibly more, rotor speeds require some additions to the current helicopter reference procedures in Chapter 8 of the Annex.

(2) Rotor Speed

In the guidelines, the rotor speed required is linked to the corresponding flight condition. This means that for take-off, approach and overflight in the helicopter mode, the higher rotor speed will have to be used, while for the overflight in aeroplane mode, the lower rotor speed has to be used.

(3) Nacelle Angle

a) *Take-off*

During take-off, the choice of the nacelle angle is left to the applicant. This is in line with the philosophy of the Annex where the choice of the configuration is left to the applicant. It is also in line with the requirement in Chapter 8 to use the aircraft's best rate of climb speed, *Vy*, since the applicant will normally choose the nacelle angle that is close to the nacelle angle that corresponds to the overall best rate of climb. Note that for each nacelle angle there is a speed that gives the best rate of climb, which is normally not the same numerical value for different nacelle angles. There will be one nacelle angle that gives the highest overall rate of climb, but this is usually not an angle that corresponds to a "gate".

b) *Overflight in helicopter mode*

In the case of overflight in helicopter mode, the definition of the nacelle angle to be used was one of the more difficult problems. Initially it was proposed to use a nacelle angle of 90°, comparable to a helicopter. This was however unsatisfactory because a tilt-rotor will normally not fly at this angle at the high speed required for noise certification. Normally the rotor will be tilted to get more forward thrust without tilting the fuselage forward and to do this, a nacelle angle of approximately 80° is selected. It was agreed that this unique capability of the tilt-rotor should be incorporated in the reference procedure. On the other hand the requirement should prevent the applicant from choosing a nacelle angle that would be close to 0° since this would give unrealistically low noise figures. Note that tilting the rotor will reduce the advancing blade tip Mach number. After long deliberations, a satisfactory solution was found. For a tilt-rotor there will normally be a nacelle angle below which hover is no longer possible and for which flight with zero airspeed is not permitted. It was decided to fix the nacelle angle for the overflight in helicopter mode to the gate closest to that angle.

c) *Overflight in aeroplane mode*

In the overflight in aeroplane mode, the nacelle angle is defined as on the down stop, the position that will normally be used for cruise and high speeds. Two conditions are measured:

– One is with the high rotor speed and the same speed as used in the helicopter mode overflight. This condition is intended to make it possible to make comparisons between the helicopter mode and aeroplane mode overflight; and

– the other condition is with the cruise rotor speed and speed V_{MCP} or V_{MO}, as defined in Note 1 of 6.3e of Attachment F of the Annex, which is intended to represent a worst case cruise condition.

d) Approach

For the approach reference configuration, the nacelle angle for maximum approach noise should be used. This is in line with the philosophy of Chapter 8 and other parts of the Annex, that require the noisiest configuration for approach. This will normally require testing several different nacelle angles in order to determine which is noisiest.

In the tilt-rotor aircraft design, the flap angle varies with airspeed so the pilot may manually set flaps or may use auto flap control in order to reduce the pilot's workload. In this latter case, the flap angle for noise certification will be the flap angle that is normal for the approach configuration and approach condition flown. For a design with pilot-controlled flap angle, the applicant should use the flap angle designated for approach and will have to prove that the noisiest configuration is used for noise certification.

GM ATT F Section 7
[Test procedures[

(1) Test Procedures

The test procedures are the same as in Chapter 8 of the Annex. Note that this means that as a minimum, all noise measurements are taken and evaluated with the microphone at 1.2 m (4 ft), including data taken for land-use planning purposes. This is proposed in order to maintain commonality with Chapter 8 numbers and to reduce costs for the applicant. If, for land-use planning or other purposes, the gathering of data at other microphone positions (i.e. at ground plane) were desired, this would of course be allowed but would have to be agreed between applicant and certificating authority.

Chapter 7

GUIDELINES ON FLIGHT TEST WINDOWS AND ADJUSTMENT OF LAND-USE PLANNING NOISE DATA MEASURED IN ACCORDANCE WITH ATTACHMENT H OF ICAO, ANNEX 16, VOLUME I

7.1 EXPLANATORY INFORMATION

7.1.1 Background

GM ATT H 1
[General]

At CAEP/6, guidelines for the provision of rotorcraft noise data for land-use planning (LUP) purposes were approved as Attachment H to the Annex. The objective of Attachment H is the provision of noise data, in metrics suitable for LUP purposes, at the noise certification flight conditions and/or at alternative flight conditions representing normal operating procedures or other flight procedures for noise abatement or heliport-specific requirements.

Detailed guidance on flight test windows and adjustments of LUP data to reference conditions for alternative flight procedures specifically designated for LUP data provision is provided in this Chapter. To be consistent with noise certification data and provide comparable accuracy, the detailed guidance is based on the flight test windows and data adjustment procedures utilized for noise certification flight procedures to the fullest extent practical.

In developing these flight test windows and data adjustment procedures, the needs associated with LUP data provision have been balanced against the test costs in acquiring LUP data with the intent of encouraging additional optional flight testing and measurements by applicants.

The guidance on test windows for alternative flight procedures is provided in 7.1.2. Guidance on adjustment of LUP data to reference conditions is provided in 7.1.3 and 7.3.1, with 7.1.3 addressing reference conditions and 7.3.1 providing specific guidance on adjustment procedures.

Note.- The test windows and adjustments to data provided in this Chapter address constant airspeed and flight path conditions only. Varying airspeed and flight path conditions may require additional guidance not yet provided in this Chapter.

7.1.2 Test Windows

GM No. 1 ATT H 2.1 & 2.2
[Alternative constant airspeed and flight path conditions]

The flight test windows and procedures for alternative constant flight conditions for LUP are provided in Table 7-1 together with the existing requirements for noise certification. "No Change" in Table 7-1 denotes the recommended use of the corresponding test window or procedure of Chapter 8 or 11 of the Annex.

Many of the flight test windows and procedures currently used for noise certification testing can be applied when acquiring noise data for LUP purposes under Attachment H of the Annex. Thus the flight test windows and procedures detailed in Table 7-1 make as much use of current adjustment procedures of Chapter 8 and Chapter 11 of the Annex, as practical. In addition, it should be noted that the "Zero Attenuation Adjustment Window" as defined in 3.2.3.2.1 may be used.

Table 7-1 includes, relative to the noise certification requirements, an expanded airspeed tolerance of ± 13 km/h (± 7 kt) for Chapter 8 helicopters, and ± 9.3 km/h (± 5 kt) for Chapter 11 helicopters (or ± 13 km/h (± 7 kt) if the Chapter 8 Δ_2 adjustment is used), and a minimum number of 4 test runs. The 90 per cent confidence interval limit of ± 1.5 EPNdB currently applied to the three-microphone average of EPNL in Chapter 8 is also applied to the corresponding three-microphone average of SEL. In the case of Chapter 11 helicopters, the current 90 per cent confidence interval requirement for the SEL at the flight track microphone is retained. In addition, the 90 per cent confidence interval calculated for each time-integrated and maximum noise level metric at each microphone should be reported.

These guidelines primarily address the balance between LUP data needs and test costs for applicants providing data under Attachment H. In particular, increasing the airspeed test window by 3.7 km/h (2 kt) will reduce test costs while incurring little impact on the final results. Reducing the required minimum number of test runs from 6 to 4 also reduces test costs while the needed accuracy of the data is maintained by the 90 per cent confidence interval limit.

GM No.2 ATT H 2.1 & 2.2
[Multi-segmented flight path conditions at constant airspeed – no climb segments]

The flight test windows and procedures provided for alternative constant flight conditions for LUP in Table 7-1 can be applied for the case of approaches with multiple reference flight path segments, each having a different constant descent angle or level flight condition. In particular, the test tolerances in Table 7-1 for total adjustments, rotor speed, airspeed, angle from the vertical, height at overhead, approach angle and test mass are applicable to each flight path segment as appropriate.

Note.- Changes in reference flight path angle between two segments should be completed as quickly as possible, in order to remain within flight path tolerances for each flight segment.. This may necessitate initiating the transition prior to the reference transition point.

GM No. 3 ATT H 2.1 & 2.2
[Multi-segmented flight path conditions at constant airspeed with climb segments]
(reserved)

GM No. 4 ATT H 2.1 & 2.2
[Non-constant airspeed and flight path conditions]
(reserved)

GM No. 5 ATT H 2.1 & 2.2
[Approaches with constant deceleration and flight path conditions]

The flight test windows and procedures provided for alternative constant flight conditions for LUP in Table 7-1 can be applied for the case of approaches with constant deceleration and flight path (glide slope) conditions with some adjustments to account for the constant variation of airspeed with time. Specifically, a reference airspeed 'schedule' – i.e., reference airspeed as a function of position along the reference flight track - needs to be derived from the reference deceleration rate for the reference condition of zero wind speed. The airspeed tolerance of +/- 7 kts should be applied to both airspeed as a function of time and as a function of position along the reference flight track as illustrated in Figures 7-1 and 7-2.

GM No. 6 ATT H 2.1 & 2.2
[Other non-constant airspeed and flight path conditions]
(reserved)

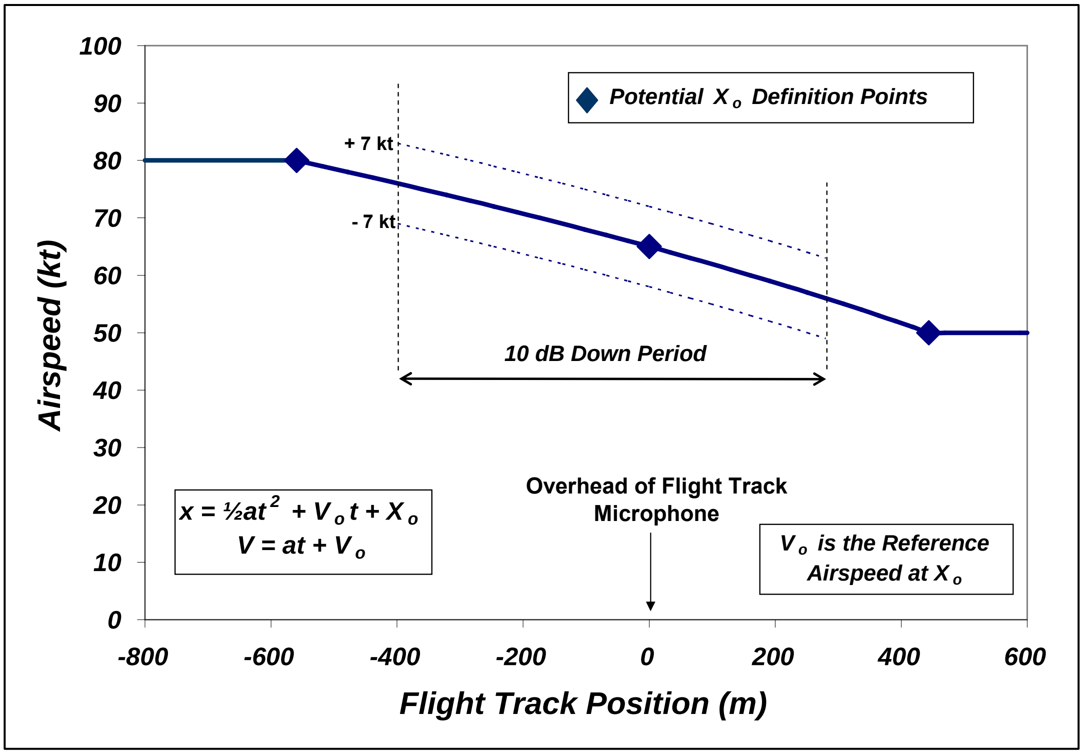


Figure 7-1 Example of a Reference Airspeed Profile vs. Flight Track Position for a Constant Deceleration from 80 kt to 50 kt at 1 kt/sec

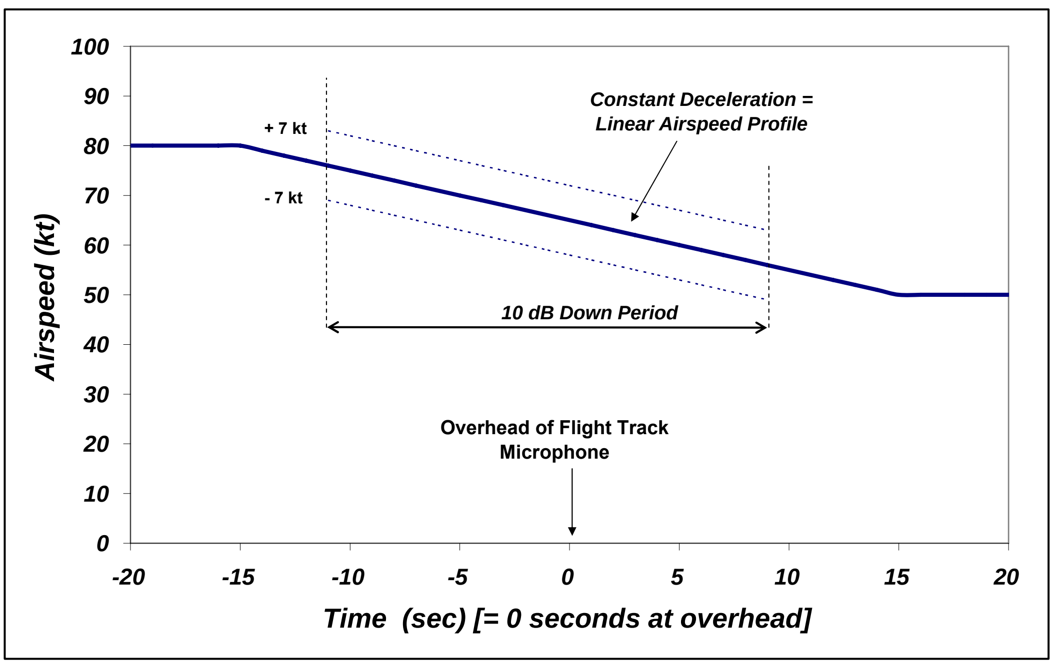


Figure 7-2 Example of a Reference Airspeed Profile vs. Time for a Constant Deceleration from 80 kt to 50 kt at 1 kt/sec

7.1.3 Reference Conditions

GM No.1 ATT H 2.3
[General]

Flight procedures designed to represent normal or noise abatement operations can vary from simple fixed flight path and airspeed procedures similar to noise certification test conditions to complex non-constant flight path and/or non-constant airspeed procedures. The resulting reference flight procedures and data adjustment procedures should be submitted to the certificating authority for approval.

The primary reference test conditions that affect adjustments to the noise data are the reference atmospheric conditions, the reference helicopter flight path, and the reference helicopter airspeed. For acquiring noise data for LUP purposes, the reference atmospheric conditions should be the same as those specified in 8.6.1.5 of Chapter 8 and 11.5.1.4 of Chapter 11 of the Annex.

In the process of developing flight profiles for land-use planning and noise abatement procedures, a reference flight path and/or reference airspeed procedure may not have been determined prior to obtaining a set of noise data suitable for land-use planning purposes. In such cases, the flight path and airspeed test data may be used to derive appropriate reference values. The method used should be approved by the certificating authority.

GM No. 2 ATT H 2.3
[Predefined constant flight path and constant airspeed]

If a predefined reference constant flight path and constant speed conditions similar to, but different from those defined for noise certification testing under Chapter 8 are used, the same adjustment procedures defined in Appendix 2 can be used with the new reference conditions substituted in the adjustment procedures as appropriate and the adjustment procedures modified as necessary to give results in terms of adjusted sound exposure level, L_{AE}, and any other metrics selected by the applicant.

GM No. 3 ATT H 2.3
[Derived constant flight path]

If a reference flight path is not predefined, a reference path needs to be derived or otherwise determined from the flight test data. One method to define the reference path is to determine the mean of the test runs by calculating the path of each test run using a least-squares linear fit of the aircraft position data, defined in terms of X, Y and Z coordinates, between the 10 dB-down points and averaging the calculated results.

An example is the case where, as a result of flight testing multiple glide slopes, a fixed glide slope approach is deemed appropriate for pilot acceptability. If the selected flight path was repeated as necessary to obtain a statistically valid set of noise levels, the flight path data can be averaged to define the reference flight path.

GM No. 4 ATT H 2.3
[Derived constant airspeed]

If the reference airspeed V_r is not predefined, a value of V_r needs to be derived or otherwise determined from the measured data. One method to define V_r is to determine the mean of the test runs by averaging of the true airspeeds (TAS) of each test run that meets the test window criteria.

An example of this is the case where the sensitivity of noise level with airspeed and rate-of-descent (ROD) is of interest. The test program might incrementally test a range of fixed indicated airspeeds for one or more rates-of-descent, with the reference airspeed for a LUP flight profile subsequently defined after the flight test program.

For the special case of determining V_r for the flyover condition when using the equivalent Mach number method (see AMC A2 8.2.2(10), 3.2.3.2.2 and AMC A4 2.4.1) to adjust for source noise, a separate method is described in GM No. 7 ATT H 2.3 in 7.3.1 of this chapter.

Note.- The reference ground speed V_{Gr} can be derived from true airspeed data as, by definition, the true airspeed and ground speed are identical for the zero wind reference condition.

GM No. 5 ATT H 2.3
[Multi-segmented flight path conditions at constant airspeed]

This guidance applies to multi-segmented approach profiles at a single constant reference airspeed, with each segment having a different reference descent angle or level flight condition.

Note.-An alternative procedure for supplying LUP data for multi-segmented flight profiles at constant airspeed is possible by combining segments from constant profile data sets. The applicant should be aware, however, that directivity effects can be important in propagating acoustic data to the flight paths for each segment, necessitating use of additional microphones to provide greater geometric resolution of the recorded noise data.

GM No. 6 ATT H 2.3
[Guidance for multi-segmented flight paths with climb segments]
(reserved)

GM No. 7 ATT H 2.3
[Non-constant airspeeds and/or flight path conditions]
(reserved)

GM No. 8 ATT H 2.3
[Approaches with constant deceleration and flight path conditions]

The deceleration phase of the reference flight profile should span the entire 10 dB-down period for each of the noise certification measurement points as illustrated in Figures 7-1 and 7-2. If not, the reference approach procedure should not be treated as a single flight segment. It is also advisable that the deceleration phase be initiated as close as possible to the start of the 10 dB down period in order to ensure that the airspeed is as close as possible to the reference airspeed at the first 10 dB down point. This will be useful in minimizing the potential effects of wind on meeting both airspeed tolerance requirements.

Note.- Practice flights may be advisable to establish and/or confirm a reference flight profile that meets these criteria.

If a reference deceleration or airspeed schedule is not predefined, its value needs to be derived or otherwise determined from the measured data. One method to define reference deceleration or airspeed schedule is to determine the mean of the test runs by averaging of the deceleration or airspeed profile of each test run that meets the test window criteria.

GM No. 9 ATT H 2.3
[Other non-constant airspeeds and/or flight path conditions]
(reserved)

7.2 EQUIVALENT PROCEDURES INFORMATION

(reserved)

7.3 TECHNICAL PROCEDURES INFORMATION

7.3.1 Adjustments to Reference Conditions

GM No. 10 ATT H 2.3
[Constant airspeed and flight path conditions]

Helicopter noise data acquired for constant airspeed and flight path conditions are typically adjusted to reference conditions using standardized procedures such as provided in Appendices 2 and 4 of the Annex.

GM No. 11 ATT H 2.3
[Measurements processed using the procedures of Appendix 2 of the Annex]

The following adjustments to noise data assume corrected as-measured one-third octave and aircraft position time history data are available in Appendix 2 of the Annex.

Note.- Corrected as-measured noise data are data corrected per the requirements of 3.9 and 3.10 of Appendix 2 of the Annex.

If a reference flight condition with a fixed flight path and/or fixed airspeed different from those defined for noise certification testing under Chapter 8 is measured, the same data adjustment procedures defined in Appendix 2 of the Annex can be used with the new reference conditions substituted in the adjustment procedures as appropriate and the adjustment procedures modified as necessary to give results in terms of sound exposure level (L_{AE}) and any other metrics selected by the applicant.

The adjustments to be applied to time-integrated noise metrics (e.g. L_{AE} or EPNdB) should include:

- bandsharing correction for tone corrected metrics such as EPNL;
- Δ_1 adjustment for sound attenuation;
- Δ_2 duration adjustment for time-integrated metrics; and
- Δ_3 source noise adjustment for overflights.

Note.- The band sharing correction, the Δ_1 adjustment and the Δ_3 adjustment should also be applied as appropriate to the maximum noise level (e.g, PNLTM, L_{Amax}) if the value is to be published.

Δ_1 can be calculated for L_{AE} and L_{Amax} as follows:

a) Determine the aircraft position at the time that the noise at L_{Amax} was emitted and the slant range to the microphone diaphragm;

b) Determine the reference aircraft position based on the reference flight path and the reference slant range to the microphone diaphragm;

c) Calculate a new reference LAmax from the one-third octave spectrum as adjusted using the equation in 8.3.1 of Appendix 2 of the Annex;

d) Calculate Δ1 by subtracting the test LAmax from the reference LAmax as in 8.3.2 of Appendix 2 of the Annex.

Note 1.- Use of the Δ_1 adjustment derived for EPNL and PNLTM is acceptable for application to L_{AE} and L_{Amax} noise data.

Note 2.- If the temperature and humidity meteorological conditions are within the zero attenuation adjustment window, the reference and test slant ranges may be replaced by the reference and test distances to the helicopter when the helicopter is over the center noise measuring point (see 3.2.3.2.1). This assumes that the measurement points are the same or close to the locations used for noise certification testing and the aircraft slant ranges are similar to those seen during noise certification testing. If additional measurement points are used that are significantly further from the flight path, consideration should be given to the increased error that is inherently added by the increased distances.

The Δ_2 adjustment is only applied to time-integrated noise metrics. The measured and reference distance values used in determining Δ_1 adjustments to the test data may be used to determine the distance term of the Δ_2 adjustment.

An example of calculating Δ_2 for L_{AE} is:

a) Determine a mean ground speed V_G for each test run;

b) If a reference ground speed VGr has not been predefined, determine a reference ground speed from the test results to be used as VGr in the Δ2 adjustment; and

c) Calculate Δ2 as in 8.4 of Appendix 2 of the Annex from the slant ranges determined from the Δ1 adjustment procedure, mean ground speed VG of the test run, and the reference ground speed VGr.

During noise certification testing, an accepted source noise adjustment procedure for overflights is the method described in 8.5 of Appendix 2 of the Annex. This adjustment is normally made using a sensitivity curve of the maximum PNLTM versus main rotor advancing blade tip Mach number. For time-integrated metrics other than EPNL the corresponding maximum noise metric should be used in place of PNLTM.

An alternative method, the equivalent Mach number test procedure, is to calculate an adjusted reference true airspeed based on the pre-selected reference airspeed and/or test airspeed and the test-day outside air temperature (see 3.1.7 AMC A2 8.2.2(10), 3.2.3.2.2 and AMC A4 2.4.1). Either method is acceptable for adjusting overflight data for LUP purposes at other speeds when the reference airspeed is known beforehand.

Note.- Use of the source noise adjustment derived for EPNL and PNLTM is acceptable for application to L_{AE} and L_{Amax} noise data.

For some overflight tests without a predefined reference airspeed V_r for which the equivalent Mach number method is intended to be used, test runs may be flown at selected airspeeds without first adjusting the airspeed for test-day outside air temperature. In this case, the reference airspeed V_r may be derived from the test data so that it includes the adjustment for source noise. This can be achieved by the following process:

a) Calculate a main rotor advancing tip Mach number M_T for each test run from the test true airspeed V_T, the main rotor blade tip rotational speed V_{TIP}, and the speed of sound c_T calculated from the on-board measurement of outside air temperature:

$$M_T = \frac{V_T + V_{TIP}}{c_T};$$

b) Calculate the mean of the test Mach numbers;

c) Set the reference Mach number MR equal to the mean of the test Mach numbers;

d) Calculate Vr from the reference Mach number MR, the main rotor blade tip rotational speed VTIP, and the speed of sound c at 25°C (77°F):

$V_r = c(M_R) - V_{TIP}$; and

e) Calculate the adjusted reference airspeed V_{ar} and Δ_2 for each test run as in the normal manner (see 3.1.7 AMC A2 8.2.2(10), 8.4.2 of Appendix 2 of the Annex and 5.2.3 of Appendix 4 of the Annex).

Note.- A value of V_r can be selected that is different from that calculated above with V_{ar} adjusted accordingly as long as each test run used to determine the mean noise level for the chosen V_r is within the test window for airspeed.

GM No. 12 ATT H 2.3
[Measurements processed using the procedures of Appendix 4 of the Annex]

Note 1.- Chapter 11 applicants are encouraged to record the sound pressure signals and/or one-third octave data and, if possible, aircraft position time history data in addition to the requirements of Appendix 4 of the Annex. This will enable additional analysis and provision of data, including additional sound metrics.

Note 2.- In addition to the center microphone required by Chapter 11, applicants should give consideration to acquiring data using two additional measurement points symmetrically disposed at 150 m (492 ft). The adjustments in this section can be applied to the noise levels measured at those locations. This requires the calculation of the slant range distance from the aircraft position at the overhead point to the sideline location.

The following adjustments assume corrected as-measured data obtained from an integrating sound level meter and aircraft position at the overhead point are available in Appendix 4 of the Annex. When as-measured one-third octave data is used to calculate L_{AE}, the method described in GM No. 7 can be used if aircraft time history position data is also available.

Note.- Corrected as-measured noise data are data corrected per the requirements of 4.3.5 of Appendix 4 of the Annex.

The adjustments to be applied to time-integrated noise metrics (e.g. L_{AE}) should include:

- Δ_1 adjustment separated into spherical spreading and duration terms (see example below); and
- Δ_2 adjustment.

Note 1.- The separation of the Δ_1 adjustment into spherical spreading and duration terms is based on the terms specified in Appendix 2 of the Annex.

Note 2.- The spherical spreading term of the Δ_1 adjustment should be applied to the maximum noise value (e.g, L_{Amax}) if the value is also to be provided.

An example of calculating Δ_1 is:

- Determine the slant range distance *SR* from the aircraft to the microphone using the measured aircraft height *H* when the helicopter is over the center noise measuring point. For the flight track microphone SR will equal H;
- Determine the reference slant range SR_{REF} to the microphone using the reference flight path; and
- Calculate spherical spreading term of Δ_{1SS} as follows:

  $\Delta_{1SS} = 20 \log (SR/SR_{REF})$.

The duration term of the Δ_1 adjustment need only be applied to the time-integrated metric and is calculated as follows:

$\Delta_{1D} = -7.5 \log (SR/SR_{REF})$.

The Δ_2 adjustment need only be applied to the time-integrated noise metric. For overflights, the equation described in 5.2.3 of Appendix 4 of the Annex and reproduced here should be used to calculate Δ_2.

$\Delta_2 = 10 \log (V_{ar}/V_r)$,

where V_{ar} is the adjusted reference true airspeed.

To calculate the Δ_2 adjustment for take-off and approach flight conditions, the ground speed of each test run is required. However neither Chapter 11 nor Appendix 4 of the Annex require measurement of the ground speed V_G. If each test run is performed with a headwind component, then it is considered acceptable that a Δ_2 adjustment need not be calculated. Note, however, that the resulting noise level will be higher than if adjusted. If ground speed is measured, then Δ_2 should be calculated using the following equation:

$\Delta_2 = 10 \log (V_G/V_r)$,

where V_r is predefined or calculated as in GM No 7 ATT H 2.3.

GM No. 13 ATT H 2.3
[Multi-segmented flight path conditions at constant airspeed]

Because of the multiple flight segments, determination of Qr to define a QrKr distance may not be feasible. Alternatively, if QrKr cannot be located on the reference flight profile, the minimum distances to the test and reference flight profiles can be used to approximate the ratio of QrKr to QK in determining the Δ1 and Δ2 adjustments. The determination of minimum distances should be made to ensure that the adjustments to data are based on distances from the corresponding flight segment on both the test and reference profiles.

GM No. 14 ATT H 2.3
[Non-constant airspeed and flight path conditions]
(reserved)

GM No. 15 ATT H 2.3
[Approaches with constant deceleration and flight path conditions]

If a predefined constant reference flight path equivalent to or similar to that defined for noise certification testing under Chapter 8 is used, the Δ_1 adjustment and the first (distance) component of Δ_2 adjustment defined in Appendix 2 of Annex 16, Volume I can be used with (i) the new reference conditions substituted as appropriate and (ii) the adjustment procedures modified as necessary to give results in terms of adjusted sound exposure level, L_{AE}, and any additional metrics selected by the applicant.

For the constant reference airspeed conditions of noise certification under Chapter 8 of Annex 16, Volume I, the second term of the Δ_2 adjustment uses a ground speed ratio to effect a duration adjustment to the measured noise levels. Because the reference airspeed is constant, this ground speed ratio is a time ratio. With a non-constant reference airspeed due to deceleration, however, a single reference ground speed is not available and the second term of the Δ_2 duration adjustment is better determined directly from reference and test time deltas defined for each test run. In this case, the Δ_2 adjustment is modified to:

$$\Delta_2 = -7.5 \log(QK/Q_rK_r) + 10 \log(\Delta t_{r,j} / \Delta t_{T,j})$$

where $\Delta t_{r,j}$ is the reference flight path time interval between the test run 10 dB-down time points and $\Delta t_{T,j}$ is the test time interval of the 10 dB-down time period for test run *j*.

Times for the first and last 10 dB-down points on the reference profile can be determined by the following procedure:

a. Distance along the reference flight profile can be represented by:

$X_r = ½ at^2 + V_0t + X_0$,

where a is the reference deceleration, V_0 is the reference airspeed at X_0 and X_0 is the selected reference flight track coordinate, typically at the initiation of the deceleration, overhead of the flight track microphone, or at the termination of the deceleration.

b. For each measurement point for each test run j, time t can be incremented until the calculated X_r coordinate agrees with the X_T coordinates of the first and last 10 dB-down points to determine the corresponding times on the reference flight profile. Alternatively, the solution to the quadratic equation can be used to directly calculate t_{first} and t_{last} as a function of x, i.e.

$$t = \frac{-V_0 + \sqrt{V_0^2 - 4(1/2a)(X_0 - x\ )}}{2(1/2a)}$$

c. $\Delta t_{r,j}$ is then given by the difference between these two time values.

GM No. 16 ATT H 2.3
[Other non-constant airspeed and flight path conditions]
(reserved)

Annex 16/ETM Paragraph	Test Window/Procedure	Noise Certification	LUP Flight Conditions
8.7.4	Total Adjustments	Take-off: 4 EPNdB/2 EPNdB Approach & Flyover: 2 EPNdB	No Change for integrated noise metrics
8.7.5	Rotor Speed (Nr)	± 1 per cent	No Change
8.7.6	Airspeed	± 9 km/h (± 5 kt)	±13 km/h (±7 kt)
8.7.7	Overflights w/ Headwind/Tailwind	equal numbers	No Change
8.7.8	Angle from the Vertical	± 10 deg or ± 20 m (± 66 ft)	No Change
8.7.9	Overflight Height @ Overhead	± 9 m (± 30 ft)	No Change
8.7.10	Approach Angle	± 0.5 deg 'Wedge'	No Change
8.7.11	Mass	90 per cent to 105 per cent	No Change
App 2, 2.2.2(b)	Temp @ 10 m (33 ft)	-10 to 35° C (14 to 95ºF)	No Change
App 2, 2.2.2(b)	RH @ 10 m (33 ft)	20 to 95 per cent	No Change
App 2, 2.2.2(c)	8 kHz Sound Attenuation Coefficient	12 dB/100 m	No Change
App 2, 2.2.2(e)	Wind @ 10 m (33 ft)	18.5 km/h (10 kt)	No Change
App 2, 2.2.2(e)	Crosswind @ 10 m (33 ft)	9 km/h (5 kt)	No Change
App 2, 3.5.2	Microphone Height	1.2 m (4 ft)	1.2 m (4 ft) (Note 1)
App 2, 5.4.2	Number of Test Runs	6	4
App 2, 5.4.2	90 per cent C.I. - 3 Microphone Average (Note 2)	± 1.5 EPNdB	± 1.5 dB SEL
	90 per cent C.I. - Each Metric at Each Mic	N/A	To Be Reported
ETM 3.2.3.2.1	No Adjustment Window	Equivalent to <0.3 dB Delta	No Change (Note 3)
ETM 3.2.3.2.2	Airspeed for Equivalent Mach No.	±5.6 km/h (3 kt)	No Change
ETM 7.1.2	Airspeed (V(t) and V(x)) - Decelerating	N/A	±13 km/h (±7 kt) of Reference Airspeed Schedule
11.6.5	Total Adjustments	2 dB(A)	No Change
11.6.6	Rotor Speed (Nr)	± 1 per cent	No Change
11.6.7	Airspeed - Constant	± 5.6 km/h (± 3 kt)	±9 km/h (5 kt) (Note 4)
11.6.4	Headwind/Tailwind	equal numbers	No Change
11.6.8	Angle from the Vertical	± 10 deg	No Change
11.5.2.1(a)	Height @ Overhead	± 15 m (± 50 ft)	No Change
	Approach Angle	n/a	±0.5 deg 'Wedge'
11.6.9	Mass	90 per cent to 105 per cent	No Change
App 4, 2.2.2(b)	Temp @ 10 m (33 ft)	-10 to 35º C (14 to 95ºF)	No Change
App 4, 2.2.2(b)	RH @ 10 m (33 ft)	20 to 95 per cent	No Change
App 4, 2.2.2(b)	8 kHz Sound Attenuation Coefficient	10 dB/100 m	No Change
App 4, 2.2.2(c)	Wind @ 10 m (33 ft)	18.5 km/h (10 kt)	No Change
App 4, 2.2.2(c)	Crosswind @ 10 m (33 ft)	9 km/h (5 kt)	No Change
App 4, 4.4.2	Microphone Height	1.2 m (4 ft)	1.2 m (4 ft) (Note 1)
App 4, 6.3.1	Number of Test Runs	6	4
App 4, 6.3.2	90 per cent Confidence Interval	± 1.5 dB SEL	No Change
	90 per cent C.I. - Each Metric at Each Mic	N/A	To Be Reported
ETM 3.2.3.2.1	Equivalent Mach No.	± 5.6 km/h (± 3 kt)	No Change
ETM 7.1.2	Airspeed (V(t) and V(x)) - Decelerating	N/A	±13 km/h (±7 kt) of Reference Airspeed Schedule

1. LUP measurements at other heights should be adjusted to 1.2 m (4 ft) using an approved method.
2. The three-microphone average is based on the three noise certification measurement points.
3. No change for Chapter 8 noise certification measurement points. Other measurement points to be evaluated.
4. Can use ± 13 km/h (± 7 kt) if velocity term of Chapter 8 Δ_2 is used.

Table 7.1

Chapter 8

GUIDELINES FOR AIRCRAFT RECERTIFICATION

8.1 INTRODUCTION

Recertification is defined as the "Certification of an aircraft, with or without revision to noise levels, to a Standard different to that which it had been originally certificated". The recertification of helicopters and light propeller driven aeroplanes to a different Standard from that to which they were originally certificated is not considered.

In the case of an aeroplane being recertificated to the Standard of Chapter 4 of Annex 16, Volume I, noise recertification should be granted on the basis that the evidence used to determine compliance is as satisfactory as the evidence expected of a new type design. In this respect the date used by a certificating authority to determine the recertification basis should be the date of acceptance of the first application for recertification.

Section 8.2 of this Chapter is concerned with the assessment of existing approved noise levels associated with applications for the recertification of an aeroplane to Chapter 4. Section 8.3 includes guidelines for the recertification to Chapter 4 of aeroplanes specially "modified" in order to achieve compliance with Chapter 4. The appropriate process for determining the compliance of a recertificated aircraft with a new Standard should be determined by the aircraft's certification noise levels and the associated substantiation document(s). A flowchart describing the process for the recertification of subsonic jet aeroplanes from Chapter 3 to Chapter 4 is presented in Figure 8-1

In the application of these recertifiction guidelines existing arrangements between certificating authorities should be respected. It is expected that bilateral arrangements will facilitate the mutual recognition between authorities of approvals granted in accordance with the guidelines recommended in this manual.

8.2 ASSESSMENT CRITERIA

8.2.1 General

Section 8.2 is concerned with the assessment of existing approved noise levels associated with applications for the recertification of an aeroplane from Chapters 3 or 5 to Chapter 4 of Annex 16, Volume I. Section 8.3 is concerned with the recertification of an aeroplane from Chapter 2 to Chapter 4 of Annex 16, Volume I. Section 8.4 is concerned with the recertification of an aeroplane from the United States Federal Aviation Administration (FAA) Part 36, Stage 3 to Chapter 4.

In applying the assessment criteria of each Section if the applicant is able to answer in the affirmative, to the satisfaction of the certificating authority, all the questions that may be relevant then reassessment is not required. The existing approved Chapter 3, Chapter 5 or Stage 3 noise levels of the aeroplane should be used to determine compliance with the new Standard. Otherwise, in order to satisfy the requirements of the certificating authority the applicant may propose additional analysis or data. Such analysis may lead to an adjustment being applied to the existing approved Chapter 3, Chapter 5 or Stage 3 noise levels. The applicant, at its discretion, may elect to provide new test data in place of, or in addition to, the analysis.

Note.- The certificating authority's assessment of the suitability of the existing approved noise levels for compliance with the requirements of Chapter 4 will include a review of any equivalencies proposed by the applicant to meet the assessment criteria.

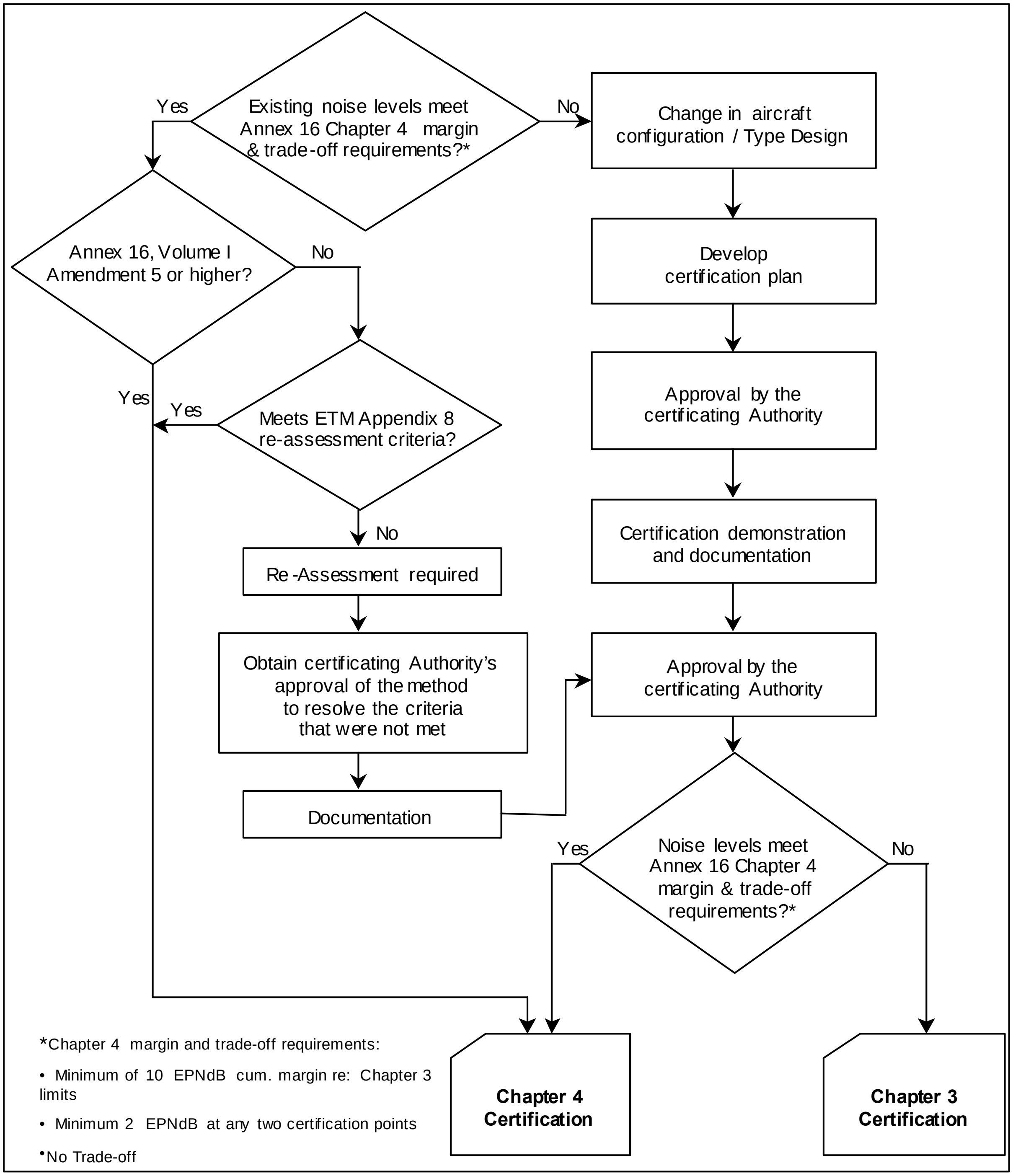


Figure 8-1 "Road Map" for recertification of subsonic jet aeroplanes

8.2.2 <u>Recertification from Chapters 3 or 5 to Chapter 4</u>

Noise levels already approved to Chapters 3 or 5 and submitted in support of applications for recertification of existing aircraft should be assessed against the criteria presented in this Section. These criteria have been developed to ensure satisfactory compliance with the new Standard. The criteria consist of a list of simple questions concerning the manner in which the original Chapter 3 or Chapter 5 data was obtained and subsequently processed. The questions are the result of a comparison of the various amendments and revisions to Annex 16, Volume I, and to this manual to which an aircraft's existing Chapter 3 and Chapter 5 noise levels may have been approved.

For aeroplanes which were approved in accordance with Amendment 5 or higher of Annex 16, Volume I, a reassessment is not required. The aeroplane's existing approved Chapter 3 or Chapter 5 noise levels should be used to determine compliance with Chapter 4.

For aeroplanes which were approved in accordance with Amendment 4 or lower of Annex 16, Volume I, the applicant should be required to show that the existing approved Chapter 3 or Chapter 5 noise levels are equivalent to those approved to Amendment 5 by answering the following questions. Note that unless otherwise noted section references refer to either Amendment 5 of the Annex or Working Group Approved Revision 6 (WGAR/6) of this manual.

For <u>all</u> aeroplanes:

a) Was full take-off power used throughout the reference flight path in the determination of the lateral noise level? (See 3.6.2.1c of Chapter 3 of Amendment 5 of Annex 16, Volume I.)

b) Was the "average engine" rather than the "minimum engine" thrust or power used in the calculation of the take-off reference flight path? (See 3.6.2.1a and 3.6.2.1g of Chapter 3 of Amendment 5 of Annex 16, Volume I.)

Note.- The applicant may demonstrate compliance with Chapter 4 requirements by determining the lateral and flyover noise levels by adding a delta dB corresponding to the difference between the average and the minimum engine, as derived from approved noise-power-distance (NPD) data based on the aeroplane performance changes due to this difference.

c) Was the "simplified" method of adjustment defined in Appendix 2 of Annex 16, Volume I, used and, if so, was -7.5 used as the factor in the calculation of the noise propagation path duration correction term? (See 9.3.3.2 in Appendix 2 of Amendment 5 of Annex 16, Volume I.)

d) Was the take-off reference speed between V2+10 kt and V2+20 kt? (See 3.6.2.1d of Chapter 3 of Amendment 5 of Annex 16, Volume I.)

Note.- The take-off reference speed used to demonstrate compliance with Chapter 4 requirements shall meet the requirements of 3.6.2.1d of Chapter 3 of Amendment 5 of the Annex.

e) Was the four half-second linear average approximation to exponential averaging used and, if so, were the 100 per cent weighting factors used? (See 3.4.5 and 3.4.6 of Appendix 2 of Amendment 5 of Annex 16, Volume I.)

Note.- The applicant is required to demonstrate compliance with the requirements of 3.4.5 of Appendix 2 of Amendment 5 of Annex 16, Volume I, which equate to an exponential averaging process for the determination of SLOW weighted sound pressure levels. Simulated SLOW weighted sound pressure levels may be obtained by using one of the two equations described in 3.4.5 and 3.4.6 of Appendix 2 of Amendment 5 of Annex 16, Volume I, as appropriate, or by other methods as approved by the certificating authority.

For jet aeroplanes only:

f) Were the noise measurements conducted at a test site below 366 m (1200 ft) and, if not, was a jet source noise correction applied? (See Appendix 6 of WGAR/6 of this manual.)

g) Do the engines have bypass ratios of more than 2 and, if not, was the peak lateral noise established by undertaking a number of flights over a range of heights? (See 2.1.3.2b in Chapter 2 of WGAR/6 of this manual.)

h) In the event that "family" certification methods were used were the 90 per cent confidence intervals for the pooling together of flight and static engine test data established according to the guidance in this manual? (See Appendix 1 of WGAR/6 of this manual.)

i) Do the engines have bypass ratios of 2 or less and, if not, in the event that "family" certification methods were used, did all associated static engine tests involve the use of a turbulence control screen (TCS) or inflow control device (ICD)? (See 2.3.3.4.1 of Chapter 2 of WGAR/6 of this manual.)

For propeller driven aeroplanes only:

j) Were symmetrical microphones used at every position along the lateral array for the determination of the peak lateral noise level? (See 3.3.2.2 of Chapter 3 of Amendment 5 of Annex 16, Volume I.)

k) Was the approach noise level demonstrated at the noisiest configuration? (See 3.6.3.1e of Chapter 3 of Amendment 5 of Annex 16, Volume I.)

l) Was the target airspeed flown during the flight tests appropriate to the actual test mass of the aeroplane? (See 3.1.2a of Chapter 3 of WGAR/6 of this manual.)

8.2.3 <u>Recertification from Chapter 2 to Chapter 4</u>

Many aircraft originally certificated to the Standards of Chapter 2 of Annex 16, Volume I, may have already been recertificated to the Standards of Chapter 3. In such a case the approved Chapter 3 noise levels may be assessed for compliance with Chapter 4 according to the criteria of 8.2 of this chapter. For a Chapter 2 aircraft not already recertificated to Chapter 3, noise data originally developed to demonstrate compliance with the requirements of Chapter 2 should first be corrected in an approved manner to the requirements of Chapter 3 of Annex 16, Volume I, before it is assessed against the requirements of Chapter 4.

In the assessment of data submitted in support of an application for the recertification of an aeroplane from Chapter 2 to Chapter 3 the recommendations of 8.3.2.1 should be followed.

8.2.4 <u>Recertification from United States FAR Part 36 Stage 3 to Chapter 4</u>

Noise levels already approved to FAA Part 36, Stage 3 and submitted in support of applications for recertification of existing aircraft to Chapter 4 should be assessed against the criteria presented as follows.

For Stage 3 aeroplanes which were approved in accordance with United States FAR Part 36, Amendment 24 (effective date 7th August 2002) or higher, the only assessment criterion of 8.2 of this chapter that may not have been satisfied is criterion g). Aside from consideration of criterion g the existing approved United States FAR Part 36, Stage 3 noise levels of the aeroplane should be used to determine compliance with Chapter 4.

For Stage 3 aeroplanes which were approved in accordance with Amendments 7 through 23 of United States FAR Part 36, in addition to the re-assessment criteria of 8.2 of this chapter, the following criteria should also be considered:

a) Was the speed component of the Effective Perceived Noise Level (EPNL) duration adjustment determined by using 10 logV/V_r? (See 9.3.3.2 of Appendix 2 of Amendment 5 of Annex 16, Volume I.0

b) For derivative engine certifications using static engine test procedures, is the summation of the magnitudes, neglecting signs, of the noise changes for the three reference certification conditions between the "flight datum" aeroplane and derived version not greater than 5 EPNdB, with a maximum 3 EPNdB at any one of the reference conditions? (See 3.2.1.3.2 of Chapter 3 of WGAR/6 of this manual).

Note.- These limitations may be exceeded under the circumstances described in 3.2.1.3.2.

8.3 RECERTIFICATION GUIDELINES

FOR "MODIFIED " AEROPLANES

An existing aeroplane may have been approved with Chapter 3 or Chapter 5 noise certification levels that are higher than the maximum levels required by Chapter 4. For such an aeroplane to be considered for recertifiction to Chapter 4, it will be necessary to "modify" the aeroplane in order to lower its noise levels below the limits required by Chapter 4. In order that certificating authorities evaluate applications for recertifiction of "modified" aeroplanes in a consistent manner, the guidelines described in this Section should be followed. These guidelines will be developed to cover other "modification" possibilities.

8.3.1 Operational Limitations

Operational limitations may be imposed on a recertificated aircraft as a condition of compliance with the new noise certification requirements. In this context, an "operational limitation" is defined as a restriction on either the configuration or manner in which an aircraft may be flown which is applied in such a way that it is dependent on the will of the pilot and may otherwise be breached.

8.3.1.1 *Flap deflection*

For the noise certification demonstration on approach:

a) Only the most critical flap deflection (i.e. that which gives the highest noise level) shall be certificated. Noise levels for other flap deflections may be approved only as supplementary information, and should be determined in conformity with 3.6.1, 3.6.3 and 3.7 of Chapter 3 of the Annex and 2.2.1.2.1 and 2.2.1.2.2 by using the same demonstrations as for the most critical flap deflection;

b) Typically for a jet aeroplane the most critical flap configuration is associated with the maximum flap deflection. If the aircraft in its original state cannot comply with the requirements at the maximum flap deflection or, if an applicant wishes to have an aircraft certificated at less than maximum deflection, the flap deflection must be limited by means of a physical limit which, for the sake of prudence, may be frangible. A simple flight manual limitation is not acceptable. It is only permitted to exceed the frangible limit in case of an emergency situation, defined here as an unforeseen situation which endangers the safety of the aeroplane or persons necessitating the violation of the operational limitation. In such cases the frangible device must be replaced according to established maintenance practices and recorded in the aircraft log, before the next flight. Reference to emergency exceedance of the frangible limit must be incorporated into only the emergency procedures section of the aircraft flight manual;

c) It is necessary to either actually fly the approach profile defined in 4.5 of Chapter 4 of the Annex or, if the reference profile is not flown, the effect of all parameters (e.g. aircraft incidence angle) that may influence the noise levels must be shown and suitable corrections to the test results applied; and

d) It should be noted that in the case of a recertificated propeller driven aeroplane, the most critical flap configuration may not be associated with the maximum flap deflection and all normally permitted flap deflections must be flown in order to determine the noisiest configuration.

8.3.1.2 *Propeller speed*

The demonstration of the noise certification level on approach must be made with the aircraft in its most critical (i.e. that which produces the highest noise level) configuration. For propeller driven aeroplanes, the configuration includes the propeller rotational speed. For a recertificated propeller driven aeroplane, only the noisiest propeller speed defined for normal operation on approach may be approved. It should not be acceptable to define an alternative normal procedure using a different "quieter", typically slower, propeller speed. A noise level for such a procedure may be approved as supplementary information only.

8.3.1.3 ***Maximum authorised take-off and landing mass***

It may be possible to lower the noise certification levels of an aeroplane by lowering its maximum authorised take-off and/or landing masses. An individual aircraft shall be certificated at only one pair of maximum take-off and landing masses at any one time. Noise levels for other masses may be approved only as supplementary information.

8.3.1.4 ***Take-off thrust de-rate***

If a de-rating in take-off thrust is used, a method for control of this thrust is required. The methods that may be available, at the discretion of the certificating authority, could include a physical or electronic control, engine re-designation, and a flight manual limitation. De-rated take-off thrust defined for noise purposes must be equal to the take-off operating thrust limit for normal operation and may be exceeded in an emergency situation. In all cases the flight manual limitations and performance sections must be consistent.

8.3.2 Demonstration Methods

8.3.2.1 ***Demonstration of lateral noise measured at 650 m***

The location of the noise measurement points for measuring lateral noise is defined in Chapter 2 of the Annex as being along a line parallel to, and 650 m (2133 ft) from, the extended runway centre line. In the case of an aeroplane recertificated to Chapter 4, but initially certificated as Chapter 2, lateral noise data taken at a lateral offset of 650 m (2133 ft) shall only be acceptable if it is corrected to an offset of 450 m (1476 ft) by means of the “integrated” method of adjustment. In such cases, at any particular time, the “measured” and “reference” emission angles must be the same.

8.3.2.2 ***Centre of gravity position during take-off***

The demonstration of approach noise level must be made with the aircraft in its most critical (i.e. noisiest) configuration. Configuration includes the location of the centre of gravity position which, for approach, is most critically fully forward. No such restriction exists for the demonstration of take-off noise levels and the applicant is therefore free to select any configuration provided it is within the normal limits defined in the flight manual. In the case of a recertificated aeroplane, the centre of gravity position used in the definition of the reference take-off profile must be within the normal certificated range.

\- - - - - - - - - - - -

APPENDIX C

Report on Curfews

A STUDY OF THE ENVIRONMENTAL EFFECTS OF CURFEWS AND OTHER NIGHT TIME RESTRICTIONS

(Prepared by Working Group 2)

SUMMARY

The following items have been presented in this study:

- A review of the issues and definition of the most important tasks.
- A brief review of changes to curfews since the CAEP/7 report especially at 6 European study airports.
- A brief review of the on-going need for curfews.
- The collection of data on flights principally at the study airports – JNB, BOM and IGI.
- An analysis of the data to isolate the effects of European curfews on direct flights to and from these three airports.
- An analysis of scheduling options between one city pair – Frankfurt and New Delhi.
- A conclusion that the curfews could be viewed as a contributing factor causing night time movements of direct flights to or from Europe at the study airports.
- However other influencing factors could include time zones, airline economics and passenger demand.

1. INTRODUCTION

1.1 This report presents the results of a study of the environmental impact of curfews and other night time restrictions conducted by Task Group 1 (TG1) of Working Group 2 (WG2) in the CAEP/8 work programme.

1.2 At the CAEP/7 meeting in February 2007, WG2 presented a study of curfews in CAEP.7.WP.015. The report provided a review of curfews including a definition, reasons for implementation, scale, scope and an extensive inventory of airports with curfews and similar operational restrictions. The CAEP/8 work programme called for further work to analyse the environmental impact of curfews. The task was identified as O.04 and read as follows:

> O.04 Estimate the environmental impact of curfews on destination countries with a case study for a major airport.

1.3 An ad hoc group was formed for this item with the aim of delivering a qualitative report on the issue. The group includes the ACI, UK, Australia, Canada, India, South Africa, EUROCONTROL and IATA. The ad hoc group proposed to undertake the following steps for the development of the report.

a) Define the problem. What are the environmental issues that are seen to be caused by curfews?

b) Review the global extent of curfews and any changes since the original 2006 study for CAEP/7.

c) Collect and analyse information that is available.

d) Draw conclusions on the effects of curfews on the environmental issues of concern.

e) Prepare a qualitative report on the above.

2. ISSUES ADDRESSED

2.1 Problem Statements

2.1.1 The ICAO secretariat informed TG1 that various discussions at the ICAO Council raised several issues that need to be addressed in this report. It is understood by TG1 that the concerns include the following items:

a) The main concern raised by Council representatives for India, South Africa and Singapore are the effects of curfews at European airports on flights to and from those countries. The TG1 participant from India confirmed that the most important issue is the night time noise generated in that country by aircraft scheduled to avoid departing or arriving during the curfew periods at European airports. Night curfews can effectively cause the transferring of night time noise burden from communities around one airport to communities around another.

b) The need for continuing noise curfews has been questioned, given that aircraft noise standards have improved over the years and the current aircraft in service are much quieter than when the curfews were instituted.

c) Night curfews are perceived as causing uneven traffic distribution within a 24 hour period and may result in non-optimal routing if capacity is exceeded. In other words, local air capacity issues may have an additional burden on emissions by concentrating traffic during day-time.

d) Airports with night curfews that are capacity constrained during day time, restrict the ability to open up new slots for additional traffic which may result in opportunity costs to airlines and airports.

e) Night curfews restrict the capability of airlines to offer flights at most convenient times (arrival or departure) to its customers, thereby reducing customer choice and adversely affecting airlines' level of service.

f) Night curfews may shift night-time operations from one airport to another. In case of airports that have excess capacity during day time, there may be additional economic costs of keeping the airport open during night-time. These costs include air and ground crew, airport operations personnel, and general support staff.

g) Night curfews can cause inconvenience to passengers if they must arrive (or depart) at night time from one airport due to restrictions on departure (or arrival) airport.

2.2 **Discussion**

2.2.1 It must be noted that TG1 is part of a technical working group, WG2, and can only address environmental issues. Issues relating to economics and passenger satisfaction cannot be properly addressed in this report.

2.2.2 Furthermore, due to limited time and resources, the TG has had to prioritise issues for this report for CAEP/8. The TG considered that the most important specific issue is the effects of curfews at European airports on night time noise at other airports and this was confirmed by the ad hoc group participants from India and South Africa. This item, as well as the reasons for the continuing need for curfews and the global extent of curfews, are the main focus of this report. From this list above this includes Items a) and b).

2.2.3 Concerns relating other environment effects such as concentration of flights causing local air quality emissions peaks, or congestion causing in-flight holding or extra pre-departure queuing and hence additional fuel burn, would need to be properly formulated and may be able to addressed during later CAEP cycles.

3. **CHANGES SINCE CAEP/7 CURFEWS STUDY**

3.1 **Global Extent of Curfews**

3.1.1 In CAEP7.WP15, the following summary of the extent of curfews (as listed in the Boeing website in 2006) was presented:

> *"1.7 The Boeing database contains information on 610 of the world's major international and regional airports, approximately half of which are in North America (310 airports). Out of the total list, about 227 airports have curfews and these are listed in the attached tables. (Note that a few airports in the database are labelled as having curfews and the details indicate that they were historic curfews which no longer apply.)*
>
> *1.8 By region approximately half of the airports (115) with curfews are in (geographical) Europe and a third (71) are in North America. The remainder are spread over all regions – Africa, Oceania, Asia and Latin America.*
>
> *1.9 Of the 30 busiest airports (by passenger number above 30 million p.a.), 18 are in North America and only 4 of these have curfews. The 6 in Europe all have curfews. Of the remaining 6 – all of which are in Asia – only 2 have curfews."*

3.1.2 As at April 2009, the Boeing web site presents information on 642 airports an increase of 32 airports since 2006. Note that some airports have disappeared from the list, while a greater number have been added. Currently there are 232 airports noted as having curfews, an increase of 5.

3.1.3 While the number of airports reported as having curfews increased by 5 (2.2%), the proportion of airports in the database decreased from 37.2% to 36.1%.

3.1.4 It must be noted that the Boeing survey labels any airport with any form of night time operational restriction as having curfew. Many of those could be reclassified as having only partial curfews.

3.1.5 Figure 3.1 contains a world map showing the airports in the Boeing database and which of those are listed as having curfews.

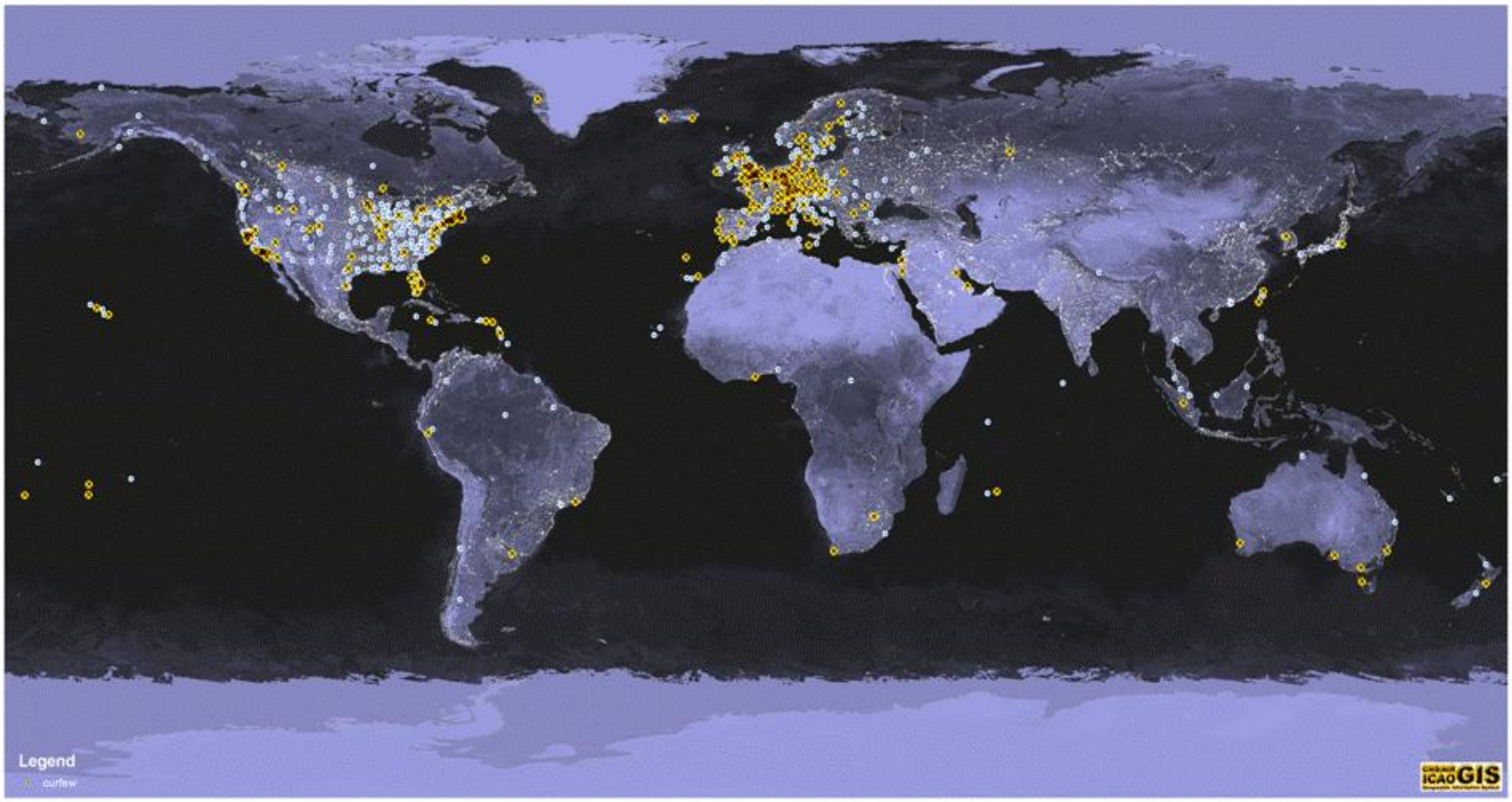


Figure 3.1 –Airport listed in the Boeing Database (April 2009)
Full or Partial Curfews (Yellow)
No curfew (Blue)

3.2 **Review of Curfews at Target Airports**

3.2.1 As discussed below the main European airports included in this study are AMS, CDG, FRA, LHR, MAD and ZHR. Information on their flight restrictions and curfews was taken from the Boeing database in late 2006 and was included in the full study presented in CAEP.7.WP.15.

3.2.2 A review of the Boeing database indicates that the majority of the curfews are unchanged as of April 2009. These are summarised in Table 3.1. The main changes appear to be at CDG where the restrictions on "Chapter 3 minus 5" aircraft has been expanded to "Chapter 3 minus 8", and at MAD where definition of night time hours has been extended. At LHR a notam supplement was issued in March 2009.

AIR-PORT	CURFEWS IN FORCE	OTHER NOISE MEASURES			
		Noise Budget Restrictions	**Noise surcharge**	**Noise Level Limits**	**Chapter 3 Restrictions**
AMS Amster-dam Schiphol	**Chapter 3 aircraft –5EPNdB:** **Aircraft equipped with engines with a bypass ratio of <3:** take off and landing not allowed between 1700-0700(1600-0600). New operations not allowed. **Aircraft equipped with engines with a bypass ratio of >3:** no planned take offs between 2200-0500(2100-0400). **Aircraft certified to Chapter 3 with margin of at least 5EPNdB:** No restrictions	Airport is fully coordinated. Capacity for summer 2006 is 270,000 mvmts. No specific noise budget	Yes (see full document for details)	See Curfew	See Curfew
CGD Charles de Gaulle Paris	**Daytime Operating Restrictions** The Chapter 3 aircraft (-5 EPNdB) may not: • land between 0615 and 2330, local time on arrival on the parking area: • take off between 0600 and 2315, departure local time from the parking area. **Night Operating Restrictions** The Chapter 3 aircraft (-8 EPNdB) may not: • land between 2330 and 0615, local time on arrival on the parking area: • take off between 2315 and 0600, departure local time from the parking area. Aircraft takeoff between 0000 and 0459, off block local time, is prohibited from this airport if a departure time slot within this time segment has not been issued. No Aircraft for which the certified noise level at the point called the "approach point", according to Standards specified in ICAO Annex 16, is more than 104.5 EPNdB, can land at the airport between 0030 and 0529, local time of arrival to parking area. No Aircraft for which the certified noise level at the point called "fly over point", according to Standards specified in ICAO Annex 16, is more than 99 EPNdB, can take off from the airport between 0000 and 0429, off block local time. (See full document for more details.) Derogations can be granted under exceptional circumstances, including delays for technical reasons outside the airline's control	Restrictions on Chapter 2	Yes – Based on aircraft's acoustic group. Additional Noise Tax.	Take off is prohibited between 0000-0459 LT unless subject to allocation of departure slot. Aircraft with noise level of more than 99EPNdB at "flyover" may take off between 0000-0459 (off blocks)	See Curfew
FRA Frankfurt	**Chapter 2:** Weekdays 1900-0700. No movements allowed from 1900 Friday – 0700 Mondays. **Chapter 3:** Take offs and landings between 2100 (2000) and 0500 (0400) are not permitted unless coordinated at least one day in advance with the Scheduling Coordinator. Landings not permitted for any kind of flights from 2300 (2200) – 0400 (0300). Exceptions apply (see full document for details.)	None.	Yes (see full document for details)	See full Document under Noise Monitoring System	See Curfew

AIR-PORT	CURFEWS IN FORCE	OTHER NOISE MEASURES			
		Noise Budget Restrictions	**Noise surcharge**	**Noise Level Limits**	**Chapter 3 Restrictions**
LHR London Heathrow	**Effective from 30/10/2006** **Quota Count System:** **QC 8 & 16** aircraft cannot be scheduled to land or take off between 2300-0700. Delayed departures may be permitted without penalty 2300-2329 LT. Unscheduled arrivals may also be permitted without penalty from 2300-2329 and from 0601-0700 LT. **QC 0.5, 1, 2 and 4:** aircraft in this group may be scheduled to operate, and may operate, during the period 2300-0700, providing the movement and quota count limits have not been exceeded.	None	Yes (see full document for details)	**Take off limits:** 0700-2300 94dBA 0600-0700 89dBA 2300-2330 89dBA 2330-0600 87dBA Penalties apply for infringements. See full document for details.	Yes (see full document under Noise Level Limits)
MAD Madrid Barajas	Departure and arrival operations classified as CR-4 and above are prohibited between 2300-0700 LT. From June 2006 a system of total noise quota is in operation from 2300-0700 (for details of classification see full document)	None	None	None	See Curfew.
ZHR Zurich	The utmost restraint will be exercised when granting authorisation for take off and landing between 2100-0500. **Departures.** Not permitted from 2330-0500. Clearance will only be granted if engines are started by 2245 UTC at the latest. Departures only permitted between 2100-2330 UTC if: - aircraft with a noise index of less than 98EPNdB are used to destinations (non-stop flights) of more than 5000 km (2800 miles) or - aircraft with a noise index of less than 96EPNdB are used for all other destinations. **Arrivals:** Landings not permitted from 2230-0500 **Private Traffic:** Departure and landing not permitted from 2100-0500. **German Airspace.** More restrictions apply for arrivals and departures over German airspace (see full document). http://www.boeing.com/commercial/noise/kloten.html#cur	None	Yes (see full document for details)	See full document for details.	None

Table 3.1: Summary of Curfews and Noise Restrictions at 6 Target European Airports from Boeing Website
(Note: Changes since CAEP/7 WP15 are shown underlined.)

4. REVIEW OF NEED FOR CURFEWS

4.1 ICAO Resolution A27-11 (1989) invites states to "consider the possible relaxation of operating restrictions for aircraft meeting the requirements of Chapter 3 of Annex 16, including the easing of night curfews and/or quotas for off-schedule arrivals by such aircraft".

4.2 Although, for a given aircraft size, an aircraft meeting the requirements of Chapter 3 is considerably quieter than one that meets the Chapter 2 requirements, aircraft have continued to grow in size and the average aircraft size has also continued to grow over time, such that in some cases, a Chapter 3 aircraft may be only marginally quieter than an aircraft that it replaces.

4.3 Secondly, since Resolution A27-11 was enacted, research has provided a greater understanding of the effects of night time aircraft noise and indicated that these effects go beyond just 'annoyance' and may lead to chronic health effects, such as hypertension and coronary heart disease, as illustrated in the 2007 ICAO 'Impacts Workshop' report and also in the more recent WHO Night Noise Guidelines for Europe (2009). If these findings are applied, the overall adverse effects will have increased in the last few decades, even in cases with reducing noise quotas.

4.4 Whilst the latest wide-body aircraft being introduced into service offer considerable noise reductions compared with earlier generation aircraft, until research into the adverse effects is better understood, there is growing pressure to extend curfews and reduce existing quotas over time rather than for a relaxation.

5. INFORMATION COLLECTED

5.1 The following information was collected during the study:

- Curfew information for all European cities (from CAEP/7 study and the Boeing website.)
- A list of scheduled direct flights between JNB and European cities (This was provided by the CAEP member for South Africa and is contained in Appendix 1.)
- A list of all scheduled flights in and out of New Delhi's Indira Ghandi International Airport (IGI) for 17 February 2009, with local arrival time in IGI and departure time from IGI and origin/ destination, separated into domestic and international categories.
- A listing of the average number of flights in and out of both BOM and JNB for all aircraft over 20 passengers, including origin/destination and time of day (either day time 7 am to 10 pm, or night time 10 pm to 7 am). This data has been extracted from MODTF's Common Operations Database (COD) for the year 2006 and due to confidentiality agreements cannot be quoted in detail.
- A listing from MODTF's COD of all flights between European cities and BOM or JNB for six specific weeks in 2006. The weeks had been selected to represent a sample of the annual data and include the weeks commencing 7 January, 31 March, 13 June, 1 August, 1 October and 22 November.

6. PROPOSED APPROACH

6.1 The proposed approach to the analysis is to undertake the following steps at the two study airports - Mumbai (BOM) and Johannesburg (JNB). Some additional analysis at New Delhi (IGI) is also included.

a) Compile data on the total flights (for a typical or average day) in and out of the airports, including data on time of day.

b) Identify which flights are directly to or from Europe and which of these are generating movements at BOM or JNB during the local night time period (10 pm to 7 am).

c) Based on the European city involved, its curfew regime and the times of departure and arrival, determine which of the flights identified in step (b) might be timed in order to comply with the curfew.

d) Assess which night time movements in BOM or JNB are being directly influenced by the curfew and estimate the difference that might occur if the curfews were not in place.

e) Assess if the curfews in Europe are resulting in the shifting of night time aircraft operation and noise burden at study airports JNB and BOM.

6.2 South Africa requested that the study also include an African city located on or near the equator. An African city with levels of traffic, in general, and European traffic, in particular, similar to that of Johannesburg was not identified and it was considered that including Mumbai in the study could be an acceptable substitute.

7. ANALYSIS AT JNB

7.1 MODTF COD

7.1.1 According to the MODTF COD (Modelling and Database Task Force Common Operations Database), there were an average of 626 daily movements at JNB in 2006 of aircraft with over 20 passenger capacity (or similarly sized freight aircraft). On average, there were 32.8 night time departures and 15.7 night time arrivals at the airport.

7.1.2 Of these movements, there was a daily average 27.6 movements of flights directly to or from European airports including, AMS, ATH, BRU, CDG, CGN, FRA, LGW, LHR, LIS, LUX, MAD, MXP and ZRH. Of these, there were an average of 3.1 night time departures and 3.5 night time arrivals. The night time period is defined as being between 2200 h and 0700 h.

7.2 MODTF COD Data for 6 Weeks in 2006

7.2.1 Table 7.1 summarises the flights between JNB and 6 European cities during the 6-week MODTF sample period. The table groups flights into departure and arrival windows (24 hour clock, local time) and show the average number of movements per week (during the 6 weeks). The number of these movements that took place during the local night time hours of 2200 h to 0700 h, both in Europe and JNB, are also shown.

		Flights from Europe to JNB					**Flights from JNB to Europe**				
	Total Flt/wk (avg)	**Dept window Europe**	**Flt/wk**		**Arr JNB**	**Nt flts /wk**	**Dept window JNB**	**Flt/wk**		**Arr Euro**	**Nt flts /wk**
			Day	**Nt**				**Day**	**Nt**		
AMS	7	10-11h	7		21-22h	1	23-01h		7	10-13h	
CDG	18	10-11h 19-20 22-24	0.3 9.5	 7.1	22-23h 06-07 09-10	0.3	19-20h 20-22 22-23	3 8.5	 0.9	07-08h 06-09 08-10	 6
FRA	16	20-22h 22-23	6.9	 7	07-09h 09-11		19-22h	13		05-07h	
LHR	34	18-19h 19-20 20-22 22-23	6.9 9.9 15	 1.7	06-08h 07-09 07-10 10-11	3.4 5.0	06-07h 07-10 20-23	 17 2	9.9 0.5	16-18h 17-19 06-08	 1
MAD	6	00-02h	6		10-12		20-22h 22-24	5	 1	06-08 07-09	3.1
ZRH	10	07-09h 19-22 22-24	0.3 3.9	 5.9	18-19h 07-10 09-11		19-22h	9.9		06-08	6.8
TOTAL FLIGHTS /WK	91 Flt/wk	**Euro Dep**		**21.7**	**JNB Arr**	**9.7**	**JNB Dep**		**19.3**	**Euro Arr**	**16.9**
TOTAL NIGHT FLIGHTS /DAY	13 Flt/day	**Euro Dep**		**3.1**	**JNB Arr**	**1.3**	**JNB Dep**		**3.5**	**Euro Arr**	**2.7**

Table 7.1 Flights between JNB and 6 Major European cities

7.2.2 The data indicates that on average JNB had 13 flights per day (26 movements) directly to or from the 6 European cities in the study. This included an average of 1.3 night time arrivals from Europe per day and 3.5 night time departures to Europe per day. At the 6 European airports there were 2.7 night time arrivals from JNB and 3.1 night time departures to JNB per day on average.

7.2.3 In summary, of the average 26 daily movements, 4.8 were at night at JNB and 5.8 were at night in Europe.

7.3 JNB – Europe Scheduled Flights

7.3.1 The data provided by South Africa (Appendix 1) lists scheduled movements between JNB and 9 European cities. There are 19 arriving and 19 departing flights listed. However, it would appear that is not a daily schedule because there are 3 flights listed for Lisbon. In general, the times of the movements, however, are consistent with the MODTF data.

7.3.2 In this schedule, 2 flights arrive at JNB at night and 3 depart JNB at night.

7.4 Discussion

7.4.1 Flying times from (western) Europe to JNB are typically 10 to 11 hours and similar in the other direction. The time zone difference is 0 to 2 hours depending on the European time zone (UK or France/Germany/Switzerland etc) and the season (summer daylight time or standard time). In general, to arrive in Europe after a morning curfew has been lifted (e.g. after 0600 h) an aircraft should depart JNB after approximately 1800 h. Therefore there is a four hour window 1800 – 2200 h available to avoid night time (2200-0700 h) departures from JNB. Aircraft that depart Europe before a night time curfew starts (2200-2300 h) will typically arrive in JNB in the late morning (0900-1100 h). (Note that all arrival and departure times are local time.)

7.4.2 This analysis indicate that there is a reasonable window available for flights between JNB and Europe to avoid night time movements at both ends in both directions. Therefore there is no evidence of an inherent link between European curfews and night time movements at JNB.

7.4.3 Table 7.1 indicates that the main cause of night time arrivals in JNB are the evening (1800-1900 h) flights out of LHR arriving before 0700 h, especially if they arrive early. In addition, late morning flights out of CDG and AMS can arrive in JNB after 2200 h. The timing of these flights, however, cannot be identified as being caused by curfews.

7.4.4 Night departures from JNB dominated by morning (0600 – 0700 h) departures to LHR. These flights arrive in the early evening (1600 – 1800 h) so the night departures in JNB can also not be as a result of Heathrow's curfew or noise quota.

8. ANALYSIS AT BOM

8.1 MODTF COD

8.1.1 According to the MODTF COD, there were an average of 541 daily movements at BOM 2006 of aircraft 20 passengers. On average, there were 86.4 night time departures and 89.0 night time arrivals.

8.1.2 Of these movements there were 34.0 movements of flights directly to or from European airports including, AMS, BRU, CDG, CGN, FRA, LHR, MXP, VIE and ZRH. Of these, there were an average of 8.0 night time departures and 11.6 night time arrivals.

8.2 MODTF Data for 6 Weeks in 2006

8.2.1 Table 8.1 summarises the flights between BOM and 7 European cities from the 6 week MODTF sample period. The table groups flights into departure and arrival windows (24 hour clock local time) and show the average number of movements per week (during the 6 weeks) and indicates which of these occurred during the local night time hours of 2200 to 0700 h, both in Europe and BOM.

		Flights from Europe to BOM					**Flights from BOM Europe**				
	Total Flt/wk (avg)	**Dep window Europe**	**Flt/wk**		**Arr BOM**	**Nt flts /wk**	**Dept window BOM**	**Flt/wk**		**Arr Euro**	**Nt flts /wk**
			Day	**Nt**				**Day**	**Nt**		
AMS	7	09-13h	7		22-02h	7	00-03h		7	06-07h	7
CDG	20.3	09-11h	6.5		22-24h	6.5	01-05h		13	07-11	
		11-13	11.7		23-01	11.7	07-10	6.5		12-15	
		13-16	1.1		01-06	1.1	11-14	1.8		16-18	
		22-23		0.8	10-11						
FRA	19.1	00-02h		1.2	13-14h		02-05h		7.2	07-10h	
		07-09	2.8		20-22		07-09	6.3		11-13	
		10-14	10		23-02	10					
		14-18	5.1		01-06	5.1					
LHR	41.3	09-11h	6.3		23-01h	6.3	10-12h	9.1		14-17h	
		11-13	11.1		00-03	11.1	13-18	2.7		16-22	
		17-18	2.3		07-08		21-22	6.1		01-03	6.1
		20-22	15		10-12		22-24		6.5	03-04	6.5
		22-24		6.3	11-13						
MXP	8.3	01-09h		1.7	13-20h		01-02		6.5	06-08	3
		09-12	6.3		22-01	6.3					
VIE	5	10-12h	5		22-24	5	00-02h		4.8	04-06h	4.8
							07-09	1.7		10-12	
ZRH	7	9-11h	7		21-23h	2	01-02h		7	06-07	7
TOTAL NIGHT FLIGHTS /WK	108 Flt/wk	**Euro Dep**		**10.0**	**BOM Arr**	**72.1**	**BOM Dep**		**52.0**	**Euro Arr**	**34.4**
TOTAL NIGHT FLIGHTS /DAY	15.4 Flt/day	**Euro Dep**		**1.4**	**BOM Arr**	**10.3**	**BOM Dep**		**7.4**	**Euro Arr**	**4.9**

Table 8.1 Flights between BOM and 7 Major European cities

8.2.2 The data indicates that on average BOM had 15.4 flights per day (30.8 movements) directly to or from the 6 European cities in the study. This is a similar level to that of JNB with 26 movements per day.

8.2.3 The BOM data included an average of 10.3 night time arrivals from Europe per day and 7.4 night time departures to Europe per day. In Europe there were 4.9 night time arrivals from BOM and 1.4 night time departures to BOM per day on average.

8.2.4 In summary, of the average 30.8 daily movements, 17.7 were at night at BOM and 6.3 were at night in Europe. Clearly, of the direct flights, there a substantially more night time movements in Mumbai than Europe. Also for a similar level of European traffic, Mumbai experiences significantly more night time movements (57%) than JNB.(18%).

8.3 **Discussion**

8.3.1 Flying times from Europe to BOM are typically 8 to 9 hours and 8 to 10 hours in the other direction. The time zone difference is 4.5 to 5.5 hours depending on the season and the city.

8.3.2 To arrive in Europe after a morning curfew has been lifted (e.g. after 0600 h) an aircraft needs to depart BOM around 0000 - 0100 h.

8.3.3 If a flight left BOM at the end of the night period (0700 h) it would arrive in Europe around 1100 h. For a fight to arrive in Europe at the end of the day, say 2200 h, before a curfew started, it would need to leave Mumbai at 1700 or 1800 h.

8.3.4 Table 8.1 indicates that the majority of night time arrivals in BOM flights leave Europe between 0900 and 1600 h. Flights that leave between 1700 and 2200 arrive in BOM between 0700 and 1200 h – day time movements in both origin and destination.

8.3.5 There some flights such as BOM-ZRH where movements are in the night time period at both origin and destination.

8.3.6 Based on this data, there does not appear to be an inherent link between European curfews and night time movements at BOM. There is no reason why a night time curfew in Europe would require a flight to leave BOM at midnight, although this might happen so passengers arrive early in the morning to make connecting flights.

8.3.7 It appears that European carriers operate flights to reach India before the activation of curfew hours and return to Europe after the curfew in order to utilize the aircraft optimally during the curfew hours. Additionally, because of the curfew, Indian carriers are also required to follow similar routines. The optimum utilization of aircraft in an international air transport is approximately 18 hours and airlines may not want to ground the aircraft during the period. However, the optimum utilization can still be achieved by adopting desired flight scheduling suggested in 8.3.3. This is considered again in more detail below.

9. **ANALYSIS AT IGI**

9.1 **Scheduled Flights for 17 February 2009**

9.1.1 According to the 1-day schedule for IGI, there were 623 scheduled movements on that day. This includes 65 night time departures and 52 night time arrivals.

9.1.2 Of these movements there were 27 movements of flights directly to or from European airports including, AMS, BRU, CDG, CPH, HEL, FRA, LHR, MXP, VIE and ZRH. Of these, on the day of the schedule, there were 10 night time departures and 10 night time arrivals.

9.1.3 Table 9.1 below allows comparison of indicative traffic volumes at JNB, BOM and IGI, noting that the source and nature of the data are quiet different for IGI.

Airport	**JNB Johannesburg**	**BOM Mumbai**	**IGI New Delhi**
Data Source	MODTF COD	MODTF COD	Schedule for 17 Feb 2009
Total Daily Movements	626	541	623
Total Night Time Movements	48	173	117
Movements of Direct Flights To or From Europe	28	34	27
Night Time Movements of Direct Flights To or From Europe	7	20	20

Table 9.1 Comparison of Traffic at 3 Study Airports

9.1.4 Table 9.1 shows that BOM and IGI have similar levels of activity. Flying times and time zone differences between New Delhi and Europe are also basically the same as those between Mumbai and Europe. The general thread of the discussion in Section 8.4 for Mumbai will similarly apply to New Delhi.

9.2 **City Pair Analysis FRA-IGI**

9.2.1 As well as looking at timing of individual flights, it is also possible to consider the circumstance where an arriving flight is reloaded with new passengers and fuel, and returns to the city of origin. Generally, an airline will prefer to conduct such a "turn-around" as quickly as possible to maximum the revenue-earning flying time of the aircraft.

9.2.2 Based on data provided by India, a German carrier has a flight that departs Frankfurt at approximately 1400 h (European Summer Time) and arrives in New Delhi around midnight (local time). The aircraft then departs IGI at 0200 h to arrive in FRA at 0700 h. Such a round trip avoids night time movements at FRA and generates two night time movements at IGI.

9.2.3 Table 9.2 examines what would happen if that pair of flights were to start at other times of the day. Departures from FRA at 24 different times during a day are listed (in the left half of the table) and the times of the consequent movements at both FRA and IGI are shown for each. For a night period defined as extending from 2200 to 0700 h, the potential night time movements are shown as shaded in the table.

9.2.4 The right hand side half of Table 9.2 show a similar set of 24 flights for an Indian carrier that might start in New Delhi and turn around in 2 hours in Frankfurt.

European Airline Turn around in Delhi				Indian Airline Turn around in FRA			
Dep FRA	Arr IGI	Dep IGI	Arr FRA	Dep IGI	Arr FRA	Dep FRA	Arr IGI
14:00	0:00	2:00	7:00	2:00	7:00	9:00	19:00
15:00	1:00	3:00	8:00	3:00	8:00	10:00	20:00
16:00	2:00	4:00	9:00	4:00	9:00	11:00	21:00
17:00	3:00	5:00	10:00	5:00	10:00	12:00	22:00
18:00	4:00	6:00	11:00	6:00	11:00	13:00	23:00
19:00	5:00	7:00	12:00	7:00	12:00	14:00	0:00
20:00	6:00	8:00	13:00	8:00	13:00	15:00	1:00
21:00	**7:00**	**9:00**	**14:00**	9:00	14:00	16:00	2:00
22:00	8:00	10:00	15:00	10:00	15:00	17:00	3:00
23:00	9:00	11:00	16:00	11:00	16:00	18:00	4:00
0:00	10:00	12:00	17:00	12:00	17:00	19:00	5:00
1:00	11:00	13:00	18:00	13:00	18:00	20:00	6:00
2:00	12:00	14:00	19:00	**14:00**	**19:00**	**21:00**	**7:00**
3:00	13:00	15:00	20:00	15:00	20:00	22:00	8:00
4:00	14:00	16:00	21:00	16:00	21:00	23:00	9:00
5:00	15:00	17:00	22:00	17:00	22:00	0:00	10:00
6:00	16:00	18:00	23:00	18:00	23:00	1:00	11:00
7:00	17:00	19:00	0:00	19:00	0:00	2:00	12:00
8:00	18:00	20:00	1:00	20:00	1:00	3:00	13:00
9:00	19:00	21:00	2:00	21:00	2:00	4:00	14:00
10:00	20:00	22:00	3:00	22:00	3:00	5:00	15:00
11:00	21:00	23:00	4:00	23:00	4:00	6:00	16:00
12:00	22:00	0:00	5:00	0:00	5:00	7:00	17:00
13:00	23:00	1:00	6:00	1:00	6:00	8:00	18:00

Table 9.2 – List of Schedule Possibilities for FRA-IGI-FRA and IGI-FRA-IGI Round Trips

9.2.5 The left half of Table 9.2 shows that the FRA-IGI-FRA round trip will generate at least one night time movement either at FRA or IGI for all departure times, except for a 2100 h departure from FRA. (This is the line shown in bold.)

9.2.6 Similarly, the IGI-FRA-IGI round trip will also generate night time movements for all starting times except one – a 1400 h departure from IGI. Incidentally, this itinerary includes the same 2100 h departure from FRA for the return flight of a German based carrier.

10. NIGHT FLIGHTS CAUSED BY CURFEWS

10.1 Identifying the Cause

10.1.1 As stated in the introduction, this report is focused on determining the extent to which European curfews are causing increased environmental impact in other countries and, specifically, night time noise in India. As this is considered to be only a "qualitative" report, the noise levels (e.g. in terms of Leq or Ldn) are not examined in detail and the issue will be approached from the point of view that, in general, night time flights cause undesirable aircraft noise and should be avoided or minimised.

10.1.2 The data in Table 9.1 shows that, for similar total daily movements, BOM and IGI have far more night time flights than JNB and, for similar numbers of direct European flights, noticeably more night time movements of flights directly to or from Europe.

10.1.3 The following discussion sets out to see if it can be determined from the data at hand, whether or not the European curfews can be identified as the cause of the high number of night time flights at IGI and BOM. The points are divided between those that indicate curfews are the principal cause of the night time movements and those that indicate otherwise.

10.2 Arguments that Curfews are the Principal Cause

10.2.1 The sheer number of night movements at BOM (and IGI) compared with those in the 6 European airports (in Table 8.1) would suggest that if the European airports did not have curfews, then the burden of night time flights might be shared more equitably between the regions.

10.2.2 Table 9.2 indicates that there are very few scheduling options available that would permit day time movements in both regions. This applies to round trips originating in both Europe or BOM/IGI. Therefore the necessity to avoid movements during the curfew times in Europe must cause the likelihood of night time movements in BOM and IGI to increase.

10.3 Arguments that Curfews are Not the Principal Cause.

10.3.1 The structure of Table 9.2 is strongly driven by the economic need to minimise the time that an aircraft spends on the ground. In theory, an aircraft could depart FRA any time between 0700 and 1200 h and arrive in IG I in the afternoon or evening. It could then depart IGI any time between 0700 and 1500 h (the next day) to arrive in FRA between 1200 and 2200 h. Such a timetable would result in only day time movements in both regions, but requires a minimum layover of 9 hours (i.e. the night time period) in India. The situation would be similar for an Indian carrier's aircraft spending the night on the ground in Europe. The cost of having the aircraft losing revenue-generating travel time might not be feasible for the airlines.

10.3.2 Table 8.1 shows that travellers from BOM to London, Paris and Frankfurt do have a choice between day time or night time departures. There might be a demand for night time flights leaving India in order to arrive in Europe in the morning to make connecting flights or business meetings.

10.3.3 Table 9.1 also shows that both BOM and IGI have substantially more night flights that JNB in general. (173/day at BOM and 117 at IGI versus 48 at JNB). This could be related to the different geographic locations of the two countries, to the markets served, or to any number of other reasons that can only be surmised.

10.4 Conclusions

10.4.1 The discussions above indicate that from the data collected there is no clear evidence that the European curfews are the principal cause of excessive night time aircraft movements in India.

10.4.2 It would be reasonable, however, to conclude European curfews are contributing to the problem and that other factors may also be part of the problem, including the time zones, airline economics and passenger demand to arrive in Europe in the morning.

— — — — — — — —

APPENDIX 1 – FLIGHT SCHEDULE BETWEEN EUROPE AND JNB

Originating From Johannesburg (JNB)

Flight No	Departure	Arrival	Aircraft	Destination
KL 592	23:55	10:00	A340-600	AMS
OA 106	20:40	05:55	A340	ATH
LH 573	18:55	05:25	B740-400	FRA
SA 260	20:20	06:15	A340-600	FRA
LH 2941	20:20	06:15	A340-600	FRA
BA 056	20:20	05:15	B747-400	LHR
SA 234	20:40	06:25	A340	LHR
BA 054	21:25	06:35	B747-400	LHR
SA 236	21:35	07:20	A340	LHR
VS 602	21:45	06:50	A340-600	LHR
TP 283	08:30	20:50	A340-300	LIS
TP 272	08:50	17:25	A340-300	LIS
TP 278	21:10	05:45	A340-300	LIS
IB 6050	22:15	07:25	A340	MAD
SA 264	20:15	07:20	A340-600	MUC
AF 994	10:30	22:00	B777	CDG
AF 995	20:30	06:00	B777	CDG
LX 289	19:20	06:10	A340-300	ZRH
SA 7242	19:20	06:10	A340-300	ZRH

Destination to Johannesburg (JNB)

Flight No	Departure	Arrival	Aircraft	~~Destination~~ ORIGIN
KL 591	10:05	21:50	A340-600	AMS
OA 105	00:55	10:10	A340	ATH
LH 572	22:35	08:50	B740-400	FRA
SA 261	20:45	08:30	A340-600	FRA
LH 2940	20:45	08:30	A340-600	FRA
BA 055	17:50	06:35	B747-400	LHR
SA 235	18:00	07:35	A340	LHR
BA 057	20:005	08:50	B747-400	LHR
SA 237	21:05	10:30	A340	LHR
VS 601	17:55	07:00	A340-600	LHR
TP 283	19:05	06:50	A340-300	LIS
TP 271	18:50	07:20	A340-300	LIS
TP 277	23:00	11:30	A340-300	LIS
IB 6051	01:30	12:35	A340	MAD
SA 265	20:55	09:05	A340-600	MUC
AF 997	00:30	10:05	B777	CDG
AF 990	23:15	10:40	B777	CDG
LX 288	22:45	10:15	A340-300	ZRH
SA 7241	22:45	10:15	A340-300	ZRH

— — — — — — — —

APPENDIX D

POPULATION/ HOUSING ENCROACHMENT IN THE VICINITY OF AIRPORTS

1. INTRODUCTION

1.1 As stated in paragraph 1.1.6 of the balanced approach guidance document, the concept of the balanced approach is based in particular on the need to preserve the benefits gained from aircraft-related measures, which may be lost if the population subsequently grows in land near airports that has been relieved. Further development of that land, if not coordinated with the expansion plans of an airport, can affect noise exposure at given traffic conditions and can lead to additional costs both to the community and to aviation.

1.2 In the A33-7 Resolution, Items 1 and 2 of Appendix F specifically relate to the issue of encroachment, wherein the Assembly:

a) "Urges States that have phased out operations of Chapter 2 aircraft at their airports as provided for in Appendix D to this Resolution, whilst preserving the benefits for local communities to the greatest extent practicable to avoid inappropriate land-use encroachment whenever possible in areas where reduction in noise levels have been achieved"; and

b) "Urges States to ensure that the potential reductions in noise levels to be gained from the introduction of quieter aircraft, particularly those complying with the new Chapter 4 standard, are also not avoidably compromised by inappropriate land-use or encroachment".

1.3 In response, the following terms of reference were proposed for examining population growth around airports:

a) assess population growth around the world's jet airports identifying and monitoring cases when the problem is most severe, elaborating historical and up-to-date analysis of these airports, reporting all measures taken to deal with noise; and

b) conduct a study of the land-use around representative airports of the world having larger numbers of impacted persons to include determination of the rate at which encroachment is or is not occurring tying encroachment to land-use management policy and enforcement.

1.4 This appendix describes the findings from a limited number of States relative to assessments of population growth and encroachment around airports. It provides an indication that encroachment has occurred and points to how the problem might be described and assessed in a systematic way. Assessing and quantifying encroachment requires that an airport maintain historical population and housing information. The following information provides an illustration of the possible means of quantifying encroachment, given the appropriate historical data.

2. **APPROACH**

2.1 Assessing development around airports requires that historical trend information be collected for both housing and population. Collecting data of this nature is a new type of process. Rather than an exhaustive inventory of airport data that would encompass the full scope of a global noise exposure model analysis, the path followed consisted in collecting data from some airports in some States where this kind of information could be obtained in support of the study. This would then prototype the requirements of a more broad scale analysis should it be required subsequently. Those able to contribute were free to submit data in any available form that could be used to assess “encroachment.” The example cases presented are based on the best historical population data that States were able to obtain within the given scope.

2.2 The term “encroachment” is used to describe growth of residential development in areas that are ‘incompatible’ or ‘potentially incompatible’ with aircraft noise. Incompatibility is defined in terms of noise exposure criteria; generally these are established locally or nationally. The analysis is straightforward when the boundary of a protected zone is demarcated to allow for future airport growth; for example, within which development would be incompatible when aircraft noise exposure reaches its forecast maximum – perhaps when traffic reached the planned ultimate capacity of the airport.

2.3 Quantifying encroachment requires definition of an incompatibility zone. Such zones are usually established by defining noise exposure contours around an airport using a noise exposure metric known to correlate with the health and welfare of people and a traffic forecast that anticipates some future growth scenario. In an ideal situation, the boundary might be developed to reflect the planned ultimate capacity of the airport. However, the reality is that forecast capacity can change over time making the tracking of encroachment in these terms difficult.

2.4 The establishment of noise zones and limiting development in the vicinity of the airport is discussed in the ICAO Document 9184, Airport Planning Manual, Chapter 2, Land Use and Environmental Control, Chapter 5. Examples from seven States are reported and in general, there appears to be two concepts, (1) establish a reference contour or noise zone based on the planned ultimate capacity of the airport and (2) establish a reference contour or noise zone based on a reasonable baseline year of traffic that could serve as a conservative estimate of future growth. In the latter, it is recognized that growth will occur, but it is difficult to predict exactly how that growth will shape future contours as capacity enhancement plans can change over time.

2.5 States participating in the study addressed the following questions:

a) Does your State have a concept of a Noise Protection Zone?

b) What authority, if any, in your State has responsibility for seeing that it is enforced?

c) Are there historical data that can track growth in this noise zone over time? If yes, can it be illustrated with an example? Can data be made available to ICAO/CAEP showing the noise zone and changes in population/housing in the zone over time?

2.6 Examples of answers to the above questions were collected from five States with the results of an examination of historical noise data provided from four States, Brazil, Japan, the United Kingdom (UK) and the United States (US). For this appendix, the airports have been labeled as "Sample Airports."

3. SUMMARY OF DATA AND ISSUES

3.1 In the above study, Brazil, Japan, the UK and the US provided examples that track population/housing growth over time. Brazil and Japan presented their information as tracked against a formal noise zone as described in the Airport Planning Manual. The UK and the US presented population changes over time as tracked against changing contours over time, which in general were receding.

3.2 The example studies presented using reference contours may not represent what all parties consider to be "encroachment" as there will be some debate on the reference contour established to which population growth should be tracked. However, the airport examples collected at the time may be used to demonstrate trends that exist at airports. Where reference contours were used, the baseline year may or may not represent a reasonable protection zone for an airport. Determining this for each airport was outside the bounds of the scope at the time. However, the years chosen in these studies represent the shrinking contour trends seen during the transition to Chapter 3 aircraft and arguably can be used to demonstrate the opportunity gained or lost by not limiting residential development in areas close to the airport.

3.3 These studies also track population and housing trends separately. In some instances, population has gone down, yet the number of housing units increased. This may be the result of a declining density per household. However, the financial obligation on aviation will most likely involve insulation or purchasing of housing units. For this reason, it may be better to define encroachment by tracking the housing counts.

4. ENCROACHMENT ASSESSMENT METHODOLOGY

4.1 Attachment A contains examples from States that have a formal definition of a noise protection zone as given in the "Airport Examples" section of the Airport Planning Manual. This is the most straightforward case since the State has formally identified a zone, which stays fixed for a long period of time. In some cases, the State has national legislation that dwellings are not permitted. Enforcement, however, at the local level did not occur, and the results are indicative of what the State could gain if the nationally developed noise zone was enforced on a local level.

4.2 Attachment B contains examples of changes in population tracked against two contour bands that were developed for two different reference years. For this analysis, the State was able to provide historical data that allowed for an examination of both population/housing and contour changes over time.

Table 1

Scenarios		Census data	
		Before	After
Contour set	Before	BASE CASE	Population change (before)
	After	Noise Change	Population change (after)
			Noise & Population Change

4.3 Table 1 above summarizes different methods of looking at population and housing growth over time and how this growth tracks against a contour that changes over time.

a) The areas shaded blue show the results of keeping one parameter fixed (contour or population) and changing a second parameter (contour or population). The box labeled ‘Noise Change’ shows the overall change in baseline population exposed to noise due to a change in contours.

b) The area shaded orange and labeled ‘Noise & Population Change’ in the right-hand column shows the combined effects of population and contours changing over time. Receding contours over time will normally result in negative numbers in these boxes as long as the distribution is not too sensitive to a change in contour shape. It is these numbers that are usually reported in airport planning projects and they usually demonstrate declining numbers of people exposed due to receding contours.

c) The boxes in the far right column labeled ‘Population Change’ show the population/housing changes relative to a fixed contour level, either the ‘before’ contour or ‘after’ contour. These sets of numbers may be considered indicative of encroachment.

4.4 Both the population change (before) and population change (after) will give a measure of population encroachment. Where the zoning remains fixed over time and covered both the smaller and larger noise contour, and provided the zoning restrictions are applied consistently, encroachment findings should be similar in both the ‘before’ and ‘after’ cases.

4.5 However, where zoning is directly linked to a noise contour, the zoned area will shrink or grow over time, depending on whether noise contours are also shrinking or growing. In the case of shrinking contours, only populations still contained inside the smaller contour will have been in the ‘zoned region’ across the two census periods. In case of growing contours, although a zone will have expanded to encompass the larger noise contour, only the region within the smaller contour will have been ‘zoned’ throughout the time period between the two censuses.

4.6 This differentiation is particularly important since census intervals are typically quite long, e.g. ten years and noise contours may change in size considerably during this period. Equally population changes may not be uniform during the period between two censuses. Thus is case of *shrinking* contours, *population (after)* is the most relevant result for illustrating population encroachment. For the case of *expanding* contours, *population (before)* is the most relevant result for illustrating population encroachment.

4.7 Population is rarely distributed uniformly around an airport and the above analysis is only valid provided the smaller noise contour is completely contained within the larger contour. Contour shape may change over time for a variety of reasons including capacity enhancements that affect the distribution of runway/flight track utilization. Where the contour shapes change considerably, additional analysis will be required to assess encroachment only within the zoned area; otherwise there is a risk of reporting the effects of population changes beyond the zoned area.

4.8 The table in Attachment B reports totals and percent changes for population and number of households over time. Numbers in parentheses are population and housing densities. Results are reported for several noise bands in order to track growth at increasing distances from the airport. However, it should be noted that not all noise bands are considered 'significant' by the State reporting the results.

4.9 The results presented in Attachment B are representative of data that was collected, although not every sample airport shows the same trend. In general, the data provides examples that may be considered indicative of encroachment.

4.10 It should be noted that the population for some of the reference years are the best estimates that were available to the task group. Although the data was the 'best available', there are some uncertainties that task group members would like to research. One State reported that the future reference year would be updated once new national numbers were officially reported. Another State used national census estimates and is continuing to research planning authorities that would 'officially' track population and housing over time and report these numbers officially for their region.

4.11 Attachment C includes additional studies from various States (Brazil, Italy, New Zealand, United States) that have been conducted since this effort concerning population encroachment near airports.

5. **CONCLUSIONS**

5.1 This exercise made on encroachment extends the details provided on the development of noise zones as provided in the Airport Planning Manual. Section 4 of this appendix presents methods of quantifying encroachment against a defined noise zone or against reference contours that may change over time.

5.2 Major elements necessary for assessing encroachment include:

a) agreement at the local level on a reasonable reference contour or noise zone (see Section 3.2);
b) if considering planned ultimate capacity of the airport, address capacity enhancements that can change over time (see Section 2.3); and
c) obtaining historical population and housing data that track growth over time.

ATTACHMENT A

Encroachment Against Formal Noise Zones

Table 2 – Sample Airports with Single Noise Zone

Year	Airport 1		Airport 2	
	Population	Households	Population	Households
1995 Census Data	149.534	63.778	110.874	48.910
2000 Census Data	145.715	65.810	116.954	53.166
Difference	-3.819	2.032	6.080	4.256
% Based on 1995	-2.6	3.2	5.5	8.7

Table 2 shows the overall changes for a single noise zone. Population and housing estimated to increase indicates that encroachment is occurring. Numbers reported are in thousands

Table 3 - Sample Airport with Multiple Noise Zones

Airport Zone	**Contour Band**	**Homes**		**Change**		**Encroachment**
		1992	**2002**	**Number Homes**	**Annual Average**	
Zone – 1	65 ≤ L < 75	2147	2735	588	2.5%	27.4%
Zone – 2	65 ≤ L < 75	6192	6203	11	0.0%	0.2%
Zone – 3	65 ≤ L < 75	1583	1282	-301	-2.1%	-19.0%
Zone – 4	65 ≤ L < 75	154	327	173	7.8%	112.3%
Zone – 5	65 ≤ L < 75	2282	3506	1224	4.4%	53.6%
Zone – 6	65 ≤ L < 75	927	1875	948	7.3%	102.3%
Zone – 7	65 ≤ L < 75	4951	5240	289	0.6%	5.8%
Zone – 8	65 ≤ L < 75	181	277	96	4.3%	53.0%
Zone – 9	65 ≤ L < 75	908	2499	1591	10.7%	175.2%
Zone – 10	65 ≤ L < 75	149	281	132	6.5%	88.6%
Zone – 11	75 ≤ L	1441	2039	598	3.5%	41.5%
Zone – 12	75 ≤ L	2632	4808	2176	6.2%	82.7%
Total		**23547**	**31072**	**7525**	**2.8%**	**32.0%**

Table 3 shows changes in number of household for 12 different zones that have varying degrees of restrictions concerning housing. For zones 4 and 8-12, it is recommended that new housing be prohibited. However, analysis using national housing counts indicates local authorities are allowing growth to occur.

ATTACHMENT B

Table 4 – Sample data for seven airports against historical reference contours

		1991 Census Data				2001 Census Data			
		Base Case				**Population Change (before)**			
		Population		Households		Population	Change	Households	Change
1991 Contours	57-60	313,390		128,448		340,009	+8%	147,028	+14%
	60-63	154,519		62,665		164,892	+7%	70,369	+12%
	63-66	74,820		29,269		80,852	+8%	33,406	+14%
	66-69	44,973		17,128		45,896	+2%	18,703	+9%
	69-72	17,847		6,982		20,031	+12%	8,378	+20%
	>72	12,394		4,869		11,413	-8%	4,698	-4%
		Noise Change (using 1991 Census)				**Population Change (after)**			
		Population	Change	Households	Change	Population	Change	Households	Change
2001 Contours	57-60	165,430	-47%	69,048	-46%	180,221	+9%	79,150	+15%
	60-63	73,675	-52%	29,368	-53%	80,648	+9%	33,721	+15%
	63-66	43,848	-41%	16,608	-43%	44,081	+1%	17,929	+8%
	66-69	18,045	-60%	6,577	-62%	19,045	+6%	7,496	+14%
	69-72	5,217	-71%	1,879	-73%	4,639	-11%	1,741	-7%
	>72	1,119	-91%	461	-91%	946	-15%	443	-4%

Noise and Population Change				
57-60	180,221	-42%	79,150	-38%
60-63	80,648	-48%	33,721	-46%
63-66	44,081	-41%	17,929	-39%
66-69	19,045	-58%	7,496	-56%
69-72	4,639	-74%	1,741	-75%
>72	946	-92%	443	-91%

1) Positive increases from 1991 to 1999 reference the 1999 contour are indicative of encroachment.
2) Decreases in population from 1991 to 1999 reference the 1991 census data are indicative of receding contours.
3) Overall decreases in population from 1991 to 1999 reference the 1999 census show the receding contours have a larger effect on reduction in people than the encroachment reported in 1) and 2).

ATTACHMENT C

Additional Studies: Below are additional studies that have been conducted concerning population encroachment near airports.

Brazil

Changes in residential and population noise exposure in the vicinities of a busy international airport were analyzed. The data used in the analysis included population/households within the areas limited by the Airport Noise Zoning Plan, which is a noise compatibility plan, for the years 1991 and 2000. The population and household data are from the census undertaken in these years. The several planning zones that make up the Airport Noise Zoning Plan were established in accordance with contour bands relative to 65 - 75 Ldn and above and also the areas limited by the local Land Use and Zoning Plan. It is important to point out that the planning zones of this airport have not changed since 1991.

Table 6 presents the population and household changes for six zones included within the $65 \leq L < 75$ band contour and for the above 75 Ldn band. Table 7 presents the planning zones restrictions.

Table 5 - Airport Population and Household Changes

ZN (Zones)	Contour Band	Census Data				Change (%)	
		1991		2000			
		Population	Household	Population	Household	Population	Household
ZN-1	**$65 \leq L < 75$**	35,364	8,569	38,549	10,460	9.01%	22.07%
ZN-2	**$65 \leq L < 75$**	733	174	1,297	351	76.96%	102.00%
ZN-3	**$65 \leq L < 75$**	14,536	3,420	22,150	5,861	52.37%	71.37%
ZN-4	**$65 \leq L < 75$**	18,474	4,739	20,307	5,756	9.92%	21.46%
ZN-5	**$65 \leq L < 75$**	7,332	1,718	11,440	2,929	56.02%	70.49%
ZN-6	**$L \geq 75$**	17,168	4,048	24,355	6,515	41.86%	60.96%
Total		93,607	22,668	118,097	31,872	26.16%	40.61%
ZN-(X)*	**$65 \leq L < 75$**	76,439	18,620	93,742	25,357	22.64%	36.18%
ZN-6	**$L \geq 75$**	17,168	4,048	24,355	6,515	41.86%	60.96%

(*) Zone defined as the aggregate of zones included within the contour band ranging from 65 to 75 Ldn.

Table 6 Airport Noise Zoning Plan Restrictions

ZN (Zones)	Contour Band	Restrictions	Encroachment	
			Population	Household
ZN-1	**65 ≤ L < 75**	Single-family dwellings allowed	9.01%	22.07%
ZN-2	**65 ≤ L < 75**	Dwellings prohibited	76.96%	102.00%
ZN-3	**65 ≤ L < 75**	Single-family dwellings allowed	52.37%	71.37%
ZN-4	**65 ≤ L < 75**	Multi-family dwellings allowed	9.92%	21.46%
ZN-5	**65 ≤ L < 75**	Dwellings prohibited	56.02%	70.49%
ZN-6	**L ≥ 75**	Dwellings prohibited	41.86%	60.96%

According to the data and diagram above, the zones that showed the smallest increase in households were the ones where dwellings are permitted (ZN-1 and ZN-4). Among the zones where dwellings are allowed, the one with the largest increase was ZN-3, in which only single-family dwellings are allowed.

On the other hand, all the zones in which households are prohibited presented a significant increase in the number of homes (ZN-2, ZN-5 and ZN-6). Note the case of zone ZN-2, which had the greatest increase in households (102%) among all the zones analyzed.

In spite of the fact that the surrounding areas affected by airport noise are, in principle, subject to control by an Airport Noise Zoning Plan, the data showed that the zone where noise level is above 75Ldn (ZN-6) presented a greater encroachment than the total remaining zones within the 65 – 75 Ldn band, although residential buildings are not permitted in that area. In fact, in less than a decade, population growth doubled and the number of houses increased to almost 61%. It is important to point out that this zone is mainly occupied by a low income population and has also slum areas, which have grown without local authority control.

The results of this analysis indicate that the land use restrictions specified in the Noise Zoning Plan are not being adequately followed. This most surely is due to the lack of commitment of the local authority responsible for the approval of buildings according to the Plan.

Therefore, this fact reinforces the need to improve not only the methodologies used in Brazil that allow for a better understanding of the dynamics of land occupation in these areas, but also the instruments to control and monitor land use.

Italy

To guarantee the agreement at local level on a noise zone and the correct land-use management from the local authorities, the national regulation calls the Italian Civil Aviation Authority (ENAC) to set up in each airport a noise airport committee, chaired by the Airport Director (ENAC) and composed of representatives from the airport operator, air traffic service provider, Environmental Protection Agency, air transport operators, and local authorities.

The committee shall present to ENAC a proposal of the noise zoning which takes into account the airport master plan and the land-use planning. The zone comes from the noise contours built on the base of the optimum air traffic scenery (in-flight and ground based operational procedures, routes, runways, distribution of the traffic, etc) identified to minimize the number of people affected by the level of noise perceived. The municipal authority has responsibility for enforcing the noise protection zone.

Table 7

Acoustic Zones	LVA limit dB(A)	Planning conditions
A	60 - 65	Residential areas allowed
B	65 - 75	Only agricultural and industrial activities allowed
C	> 75	Only airport activities allowed

At Bologna International Airport, the noise protection zone was approved by the Committee in 2003, and it has a more extended surface with respect to the acoustic map. The local Municipal Authority enforced the noise protection zone in the same year. At that time, residential areas around the airport were characterised by high density, most of the land included in the noise contours was already urbanized. In order to limit an increase of people affected by the noise levels, the municipal authority decided to extend land use restrictions in zone A, even limiting future changes in the use of existing buildings and avoiding that service buildings could be assigned for residential use.

In zone B, new residential buildings are forbidden, and in the case of housing renovations, the increase of the residential surface is not allowed. Also, noise sensitive land uses, such as hospitals, schools etc, are not allowed.

In 2004, the Bologna Airport's east side runway was extended 350 meters, reaching a length of 2800 meters. As a consequence, departing aircraft fly over Bologna at higher altitudes, with benefits in terms of noise and visual impact. The noise zone was not modified.

The following Table 9 shows the population assessment, based on census estimates, referring to the number of people exposed within each set of noise contours. In absence of data about number of dwellings, the municipal Authority has supplied the number of street numbers (civic number).

Table 8

SCENARIOS		2002 CENSUS DATA (1)				2008 CENSUS DATA (2)			
		BASE CASE				***POPULATION CHANGE (before)***			
		POPULATION		**CIVIC NUMBER**		**POPULATION**		**CIVIC NUMBER**	
2002 CONTOURS	**60 – 65 (zone A)**	4395		508		4151	-6%	527	4%
	65 – 75 (zone B)	1362		172		1293	-5%	175	2%
	> 75 (zone C)	0		0		0			
		NOISE CHANGE (3)				***POPULATION CHANGE (after) (4)***			
		POPULATION		**CIVIC NUMBER**		**POPULATION**		**CIVIC NUMBER**	
2008 CONTOURS	**60 – 65 (zone A)**	3363	-23%	367	-28%	3159	-6%	378	3%
	65 – 75 (zone B)	31	-98%	17	-90%	23	-26%	17	0%
	> 75 (zone C)	0		0		0		0	

	NOISE AND POPULATION CHANGE (5)			
	POPULATION		**CIVIC NUMBER**	
60 - 65	3159	-28%	378	-26%
65 - 75	23	-98%	17	-90%
> 75	0		0	

1) Low decreases from 2002 to 2008 (1) (2) census data referring to 2002 contours and low decreases from 2002 to 2008 (3) (4) census data referring to 2008 contours indicate that over time population has not substantially changed due to the efficient land use management policy.

Note: The low increase of civic numbers is registered from 2002 and 2003 (noise zoning enforcement date)

2) Overall decreases in population and civic numbers from 2002 to 2008 (1) (5) referring to 2002 are indicative of receding contours, due to runway extension

The following Table 10 presents the population changes over time within the areas limited by the Noise Protection Zone which has a more extended surface with respect to the acoustic map. It is important to point out that the planning zones have not changed over the years even though the acoustic map receded due to the runway extension

Table 9

		Extension (kmq)	Population	% Var Population	Street Numbers	% Var Street Numbers
Acoustic Zones (A+B+C)	**2003**	12,186	9683	-	1290	-
	2005	12,186	9567	-1,20%	1319	2,25%
	2008	12,186	9368	-3,25%	1346	4,34%

New Zealand

In 1999, Auckland International Airport Limited (AIAL) conducted an airport noise study based on the construction of a new second runway parallel to the existing runway. Case studies for the years 1993, 2010, 2020, and 2030 were conducted. The purpose of this case study is to provide an example of how an airport can take predicted population changes into account when conducting airport noise studies involving future operational scenarios.

Among other analyses, the estimates of current and future impacts of airport noise included a study on the number of dwellings and residents within the calculated airport noise contours. The analysis considered the noise areas, namely, within the 65 Ldn noise contour, between 60 and 65 Ldn, and between 55 and 60 Ldn.

The process involved two steps. The first was to estimate the number of dwelling within each area for each case and the second was to estimate the number of residents in those dwellings.

<u>Number of Dwellings</u>

The local authority, Manukau City Council, had a GIS (Geographical Information System) that was able to compute the number of properties zoned Residential, Rural 1 or Rural 2. In the Rural zones the total areas could also be calculated.

Two different dwelling development scenarios were considered as follows:

No Growth – This scenario calculated the number of dwellings in each of the noise areas for each of the four cases, based on the zoning of each property. Each separate property zoned either Residential (Res) or Rural (R1 or R2) was taken as having just one dwelling.

Predicted Growth – This growth scenario was calculated only for the 2030 Case and used two sources of data for the projections. The first was a Change in Population study published by the national Government body, Statistics New Zealand, which estimated that the population of the regional would grow between 20 and 52% in the period 1996-2031. The second was the Rural 2 zoned land would be permitted to be subdivided for residential purposes at an average rate of 650 m^2 per dwelling (including amenities such as roads.)

The results were as tabulated below in Table 11 (Note that these are slightly abridged from the original report for the purposes of brevity and simplicity.)

Table 10

Case	Noise Area (Ldn dBA)	No Growth Scenario				Predicted Growth Scenario		
		Number of Properties of each Zone type			# Dwellings	Stats NZ Pop'ln Growth (Res only)	Rural 2 Sub-division	# Dwellings in 2030
		Res	R1	R2				
1993	55-60	1884		6	**1890**			
	60-65	225			**225**			
	>65							
2010	55-60	2693	8	87	**2788**			
	60-65	950			**950**			
	>65	43			**43**			
2020	55-60	2609	20	97	**2726**			
	60-65	1040			**1040**			
	>65	131			**131**			
2030	55-60	4019	46	106	**4171**	30%	8400	**13625**
	60-65	1578		17	**1595**	20%	1739	**3632**
	>65	183			**183**	20%		**220**

The tabulated results show that the future subdivision of Rural 2 land shows a substantial potential for new dwellings in the Noise Areas between 55 and 65 Ldn. Over 10,000 new dwellings could result in a three-fold increase in the number of dwellings compared with the "No Growth" scenario.

<u>Number of Residents</u>

The second step in the process was to estimate the number of residents. According to Statistics New Zealand, the average number of people living in each dwelling at the time of the study was 3.1. By 2030, that figure is expected to drop to 2.9.

Using these figures and those in the above table, it was a simple step to determine the number of residents in each of the noise areas for each of the study years and growth scenarios.

United States

Research was conducted on population and land use patterns around 92 US commercial airports between 1990 and 2000. The research examined how these patterns have responded to federal planning efforts to curtail residential development on land inside the 65 Ldn noise contours and the role land use planning had in reducing total noise exposure during the phase-out of older, louder Stage 2 aircraft. The purpose of the research was to determine the extent to which residential populations are aggregating near airports.

The results showed that land use planning has mixed results deterring residential development on land inside the existing 65 Ldn noise contours. Also, it found that land use planning has done little to address the increasing population aggregation on lands near the existing noise footprint. The conclusions of the study indicated that population within the 65 Ldn noise contour appeared to be controlled, whereas the population outside the 65 Ldn noise contour was increasing and showing evidence of encroachment. The findings are explained in more detail in a report entitled "Airports and Their Cities: The Effectiveness of Mitigating Noise Exposure through Land Use Planning, 1990-2000," by Wyle Laboratories prepared for the Federal Aviation Administration.

In follow-up research, an analysis into the underlying factors that influence residential land use near 71 commercial airports was conducted. In particular, it examined the relationship between changing residential housing densities near commercial airports and factors commonly attributed to suburbanization and sprawl. The research used a principle components analysis and a series of multiple linear regression models to analyze factors commonly attributed as the source of shifting residential development. The main conclusion of the study indicates that there is a strong relationship between employment opportunities and residential housing near commercial airports. It found that efforts to mitigate noise exposure by promoting large economic zones around airports have created an unintended result of people relocating to be near their employment centers.

— — — — — — — —

Agenda Item 5: Future work

5.1 INTRODUCTION

5.1.1 The Secretary General of ICAO addressed the meeting expressing his personal commitment to aviation environmental issues and assured the group that the necessary Secretariat resources would be made available to provide the proper support to the work programme of CAEP. He further congratulated the meeting for the large amount of work it carried out and stated that he was impressed by its achievements. He thanked the members and observers for the support that they have offered in support of CAEP. He explained the importance of the future work of the Committee for ICAO's leadership in the environment field and offered his best wishes for the remainder of the meeting.

5.1.2 The Director of the Air Transport Bureau thanked the members and observers of CAEP for their hard work during the current cycle and for their dedication that resulted in the great progress made during the meeting. She wished the committee similar success during the next CAEP cycle.

5.1.3 In his introduction to the agenda item on future work, the Chair noted that resources are a key issue and that the discussion under this agenda item would need also to focus on the prioritization of tasks and on what resources are available to carry out the work.

5.2 ICAO COLLOQUIUM ON AVIATION EMISSIONS AND 2010 ENVIRONMENTAL REPORT

5.2.1 The Secretary presented an overview of the upcoming ICAO Colloquium on Aviation and Climate Change that will be held from 11 to 14 May 2010. The Secretary also informed the meeting on the development of the second ICAO Environmental Report, to be entirely dedicated to aviation and climate change, expected to be issued in June 2010. She noted that the support from CAEP members, observers, and the working groups will be key to the success of these two initiatives and she strongly encouraged their support to the Secretariat in these two main initiatives.

5.2.2 Discussions and conclusions

5.2.3 A member mentioned her State's support to several ICAO events related to the environment in the past and informed the meeting that they will continue to support the Secretariat in these types of activities. She suggested that, following the successful way in which the CAAF2009 was organized, that a similar process of having a planning committee to work on the Colloquium agenda be put into place to assure that the necessary resources are made available in advance.

5.2.4 An observer, while acknowledging the value of both the Colloquium and the Environmental Report, suggested that this request for support be integrated in the CAEP future work programme in order to have better coordination and assignment of the available resources and the scheduling of activities.

5.2.5 Other members expressed support for initiatives that provide technical information on the area of aviation and environment and welcomed the information about the upcoming Colloquium. A member suggested that the Colloquium include the topic of alternative fuels.

5.3 PREPARATION OF THE WORK PROGRAMME

5.3.1 The Secretary presented a general work programme that reflected the input from the Working Groups along with the items recommended by the HLM and CAAF2009.

5.3.2 Noting the importance of planning and identifying priorities for the CAEP/9 work programme, the Secretariat began planning the CAEP future work programme during the 2009 Steering Group meeting. She recognized the increasing workload in the environmental area and this pre-planning should permit better consideration by CAEP participants of schedules and budgets for undertaking CAEP-related activities.

5.3.3 A member reiterated that the results of the High level meeting were taken very seriously and that her State is already working on the issues identified by that meeting, in particular to work on a CO_2 Standard.

5.3.4 A member presented recommendations on enhancing CAEP processes for handling tasks of high importance and addressing matters of lesser priority following the 2009 Steering Group Meeting. She noted that during that meeting, following the process put forward by the CAEP Secretary, five priorities were identified:

a) Climate change (CO_2 standard, efficiency metric, and related tasks from the HLM);

b) Noise (maintenance of CAEP's core function to update Annex 16, Volume 1);

c) Particulate matter;

d) Evaluation of new technologies, including Independent Experts processes; and

e) Tools, databases, and forecasts.

5.3.5 She noted that these represent a significant amount of work that need to be taken in a coordinated manner. She presented several suggestions on process improvement intending to enhance the quality of and access to CAEP's work and, ultimately, leading to an increased likelihood of successful achievement of the CAEP/9 work programme. She suggested that the work of the Committee focuses on accelerating high priority tasks and having clear timelines.

5.3.6 The member also mentioned the importance of holding annual Steering Group Meetings in order to allow the Steering Group to agree to specific programme elements or designs including making key decisions or providing recommendations to Council. She expressed the opinion that given the heightened global interest in international aviation emissions, but equally applicable to noise considerations, that the CAEP's work should be open to being informed by a wider range of experts.

5.3.7 The member also asked for greater transparency to the CAEP process. Given the increased interest in the CAEP's work, in particular that which is climate-related, she noted that it seems increasingly important to allow full access to evolving work in order to inform States, observers and the public, as well as to receive valuable contributions from entities that would not otherwise have access to CAEP materials. Such action would also allow interested States, organizations, and the public not able to participate in CAEP to keep abreast of CAEP's work. She recommended that as a pilot program, the work related to the CO_2 emission standard task be made available to the public in this manner. As an example, this could be accomplished by making Summaries of Discussions (SD) or other forms of meeting records from the CO_2 emission standard task group, WG3, MODTF, and FESG related to the progress toward a CO_2 emission standard available to the public.

5.3.8 An observer presented his position on further continuing to work on noise stringency. He acknowledged that some of these views have already being discussed during the meeting. In his view there are three main priorities for the CAEP/9 cycle:

1) to work on the CO_2 Standard;

2) to continue working on noise stringency; and

3) to work on Particulate Matter.

5.3.9 Although not on this list, he noted that the work on interdependencies between emissions and noise should also be considered a priority.

5.3.10 When talking about lower priority issues, however he requested the Committee not to lose sight of the issue of cruise NO_x emissions as technologies develop for addressing LTO NO_x emissions to verify that the relationship between LTO NO_x and cruise NO_x emissions remains close as it has been in the past.

5.3.11 The observer fully supported the views on improving the process of transparency.

5.3.12 A member supported suggested that CAEP should move away from the 3-year cycle. He noted that if CAEP were to work on an annual cycle that the duration of CAEP meetings could be reduced. He supported having ICAO publications being produced only electronically and made publicly available.

5.3.13 An observer, noting that many CAEP members were in support of this position, expressed that in his view it would be premature to consider a new noise stringency during CAEP/9 for the following reasons:

a) a determination needs to be made whether a new stringency should be based on cumulative margin approach or at each certification point;

b) the current certification status of next generation technologies;

c) potential tradeoffs in light of the upcoming CO_2 Standard;

d) a noise stringency could preclude introduction of promising technologies like open rotor engines that could deliver significant environmental benefits in other areas;

e) potential effects of the standard on the fleets in developing countries; and

f) the economic situation of world’s airlines.

5.3.14 The observer was under the impression that these views were not appropriately balanced in the outcomes of the discussions, but he clarified that he would not oppose exploratory analysis to support the development of a stringency after CAEP/9, however.

5.3.15 An observer agreed that it is premature to decide now that a new noise stringency will be agreed at CAEP/9, but that it cannot be decided now that it will be premature to take such a decision at CAEP/9.

5.3.16 Another observer expressed that many States also support a CO_2 Standard and noise stringency assessment in CAEP/9 and that the points raised could be read in two ways, and therefore, were also a good reason for undertaking such work.

5.3.17 A member noted that there is a degree of agreement and a degree of disagreement, on advancing with more stringent Standards and he requested that equity and the concerns of the observer be taken into account in the future work programme. He noted in particular the difficulties related to the fleets in developing countries.

5.3.18 An observer expressed concerns about having the contents of the CAEP web site made available to the public. He mentioned that papers are posted in an intermediate format and there are serious concerns of having data misinterpreted before a final position had been determined by CAEP. He stated that if CAEP were to make the contents of its website publicly available, his organization would need to rethink whether they could provide data to support the process.

5.3.19 A member stated that having a priority on climate change does not preclude having CAEP working on other important issues, he noted that there are a lot of important aspects to aviation so even if CO_2 is the priority issue at present, CAEP should not overlook other important environmental concerns, like noise and PM noting they are also constraints to growth.

5.3.20 The FESG Co-Rapporteur echoed the concerns of having CAEP documents made publicly available as this would stifle the exchange of views in the meeting.

5.3.21 The Secretary provided some background on the need for the secure websites and on ICAO publications. A decision of having only electronic publications would need to be considered at a higher level.

5.3.22 The Co-Rapporteurs of WG1 presented on future work for their group.

5.3.23 An observer presented a proposal on future work related to operations.

5.3.24 The WG3 Co-Rapporteurs presented future work for their group emphasising the high priority list identified in Salvador. The meeting noted the high workload of the group given the efforts on goals for fuel burn, new Standards, certification and items related to PM. The meeting also noted the resource constraints associated with the need for WG3 to provide support to other working groups.

5.3.25 The Secretary informed the meeting of a request from Mexico. Mexico is conducting a review of their infrastructure, including airports that could potentially be affected by rising sea levels and requested that this work be brought to the attention of this meeting, as States could benefit from guidance from the Committee to address adaptation to climate change for the aviation sector. An observer noted that the impact of climate change impact on aviation is an issue of growing importance and that EASA will host an international conference on this issue with a particular focus on safety aspects. The Secretariat will distribute information on the EASA conference.

5.3.26 The Chair noted that the meeting already agreed to the priority of carrying out work on the following items:

1) CO_2 Standard;

2) Particulate Matter; and

3) Noise;

5.3.27 The meeting was reminded that agreement was still needed on several matters including the formation of an Impacts Task Force (ITF), and forecast issues.

5.3.28 An observer requested the meeting to consider delaying the IE final review in light of the priority to be given to the CO_2 Standard task.

5.4 ADMINISTRATIVE

5.4.1 Participation in CAEP meetings

5.4.1.1 The Secretary noted that that there was broad support for increased participation in the work groups. To facilitate the additional participation, the Secretariat will issue State Letters seeking support from governments and it will facilitate access to working group meetings by conference calls. The Secretariat will also be monitoring closely the participation within the groups and will be informing the ICAO Council on this matter on a regular basis.

5.4.2 Documentation

5.4.2.1 The Secretary will propose a procedure to be adopted by CAEP regarding the submission of documentation to CAEP-related meetings to the first Steering Group meeting after CAEP/8. This proposal will include deadlines for submissions of documentation from working groups, as well as the timeline for preparing and for the length of the main reports. In addition, it will propose deadlines for the submission of position papers. This approach is intended to allow the CAEP participants to consider the material with the necessary time to be well prepared for discussions.

5.4.2.2 The Secretary will further consider the issue of more widely disclosing CAEP-related documents, taking into consideration the views expressed by the meeting on the need to balance transparency and the protection of information during the preparation of CAEP work.

5.4.3 Priorities

5.4.3.1 The meeting was informed that the priorities for CAEP/9 resulting from the Members Only Meeting were: the development of a CO_2 Standard, work on noise, and work on PM as had previously been agreed by the meeting. The Members Only Meeting determined that there would be no need for a full new forecast and a full new goals assessment during CAEP/9, but that some lighter goals runs may be needed. The Members Only Meeting also agreed that work on the carbon calculator should continue as should the work on operations.

5.5 CAEP STRUCTURE

5.5.1 The meeting agreed to the following structure for CAEP/9:

a) Working Group 1 (WG1) – Noise technical;

b) Working Group 2 (WG2) – Operations;

c) Working Group 3 (WG3) – Performance and Emissions, which will include task groups on the development of a CO_2 Standard and on particulate matter;

d) Forecasting and Economic Analysis Support Group (FESG);

e) Modelling and Databases Group (MDG);

f) Impacts and Science Group (ISG); and

g) Aviation Carbon Calculator Support Group (ACCS).

5.5.2 The Chair explained that subgroups could be created within the above groups as required. Building upon this basic structure and guidance, the working groups need to further establish the appropriate WG structure to address the their work programmes.

5.5.3 The meeting agreed to the following Co-Rapporteurs:

a) WG1 – Mr. Willem Franken (EASA) and Dr. Raquel Girvin (United States);

b) WG2 – Mr. Ted Elliff (Eurocontrol) and a representative from the United States;

c) WG3 – Mr. Curtis Holsclaw (United States) and Dr. David Lister (UK) and as CO_2 Standard Task Group Leaders – Mr. Matt Spears (United States) and Mr. Steve Arrowsmith (EASA)

d) FESG – Ms. Sylvie Mallet (Canada) and Mr. Jorge Silveira (Brazil);

e) MDG – Mr. Gregg Fleming (United States) and Dr. Urs Ziegler (Switzerland);

f) ISG – Dr. Lourdes Maurice (United States) and Prof. David Lee (UK);

g) ACCS – Mr. Tim Johnson (ICSA) and Mr. Alexandre Filizola (Brazil).

5.5.4 The meeting agreed that Mr. Tetsu Shimizu will continue to be the Focal Point on Voluntary Measures.

5.5.5 The Chair also explained that Independent Experts groups for Fuel Burn Improvement Technology and Air Traffic Operational Goals would be established. These groups would remain independent; reporting directly to CAEP, but WG3 and WG2 respectively, would provide the necessary support. Initial scope and working methods for conducting the CAEP/9 air traffic operational goals review is included in Appendix H

5.5.6 The meeting recalled that a decision was already taken and that an Independent Experts fuel burn technology review will be held in May 2010.

5.6 CAEP/9 WORK PROGRAMME

5.6.1 The meeting considered the work programme presented by each of the groups and approved the work programme items shown in the appendices at the end of the report on this agenda item.

Appendix A: tasks related to noise (WG1);

Appendix B: tasks related to operations (WG2);

Appendix C: tasks related to emissions (WG3);

Appendix D: tasks related to forecasting and economic studies (FESG);

Appendix E: tasks related to modelling and databases (MDG);

Appendix F: tasks related to scientific input to CAEP (ISG); and

Appendix G: tasks related to carbon calculator (ACCS).

5.6.2 The meeting was reminded that in developing the new work programme, special attention needed to be given to the resources available, the priority and relevance of tasks, and a clear definition of the end products envisaged.

5.6.3 The meeting developed the following recommendation:

Recommendation 5/1 —Revised CAEP work programme

That the Council approve the revised work programme of CAEP contained in Appendices A to G of the report on this agenda item.

5.6.4 In light of the CAAF2009 results, the Secretariat will continue to follow developments in the field of alternative fuels, noting that CAEP members and observers are welcome to participate in this Secretariat-led activity. The Secretariat will keep CAEP informed of progress in this area.

5.6.5 Noting that there will be no tasks related to land use planning or the Balanced Approach, the Secretariat will act as the focal point on these issues during the CAEP/9 cycle.

5.6.6 Items related to adaptation would be followed up by the Secretariat, who will report on developments to CAEP. A member and an observer informed that they have information to share on this topic.

5.6.7 The meeting noted that although the work of the Market-based Measures Task Force was complete, there are items that may require an update after CAEP/9. The Secretariat will keep track of those items and bring them to CAEP's attention as appropriate.

5.6.8 The meeting reaffirmed that the remit of WG2 is limited to: Independent Expert Operational Goals Review, Updates to Circular 303, and CNS/ATM Environmental Assessment Best Practices and High-Level Principles.

5.6.9 The meeting noted the concerns expressed by an observer on the CO_2 and noise standards related to future work.

5.7 SCHEDULE OF ACTIVITIES

5.7.1 One main challenge for CAEP/9 is the development of different priority tasks simultaneously. Therefore, the meeting discussed extensively how such tasks could be undertaken and delivered by the end of the CAEP/9 cycle. Below is a tentative timeline of main CAEP activities:

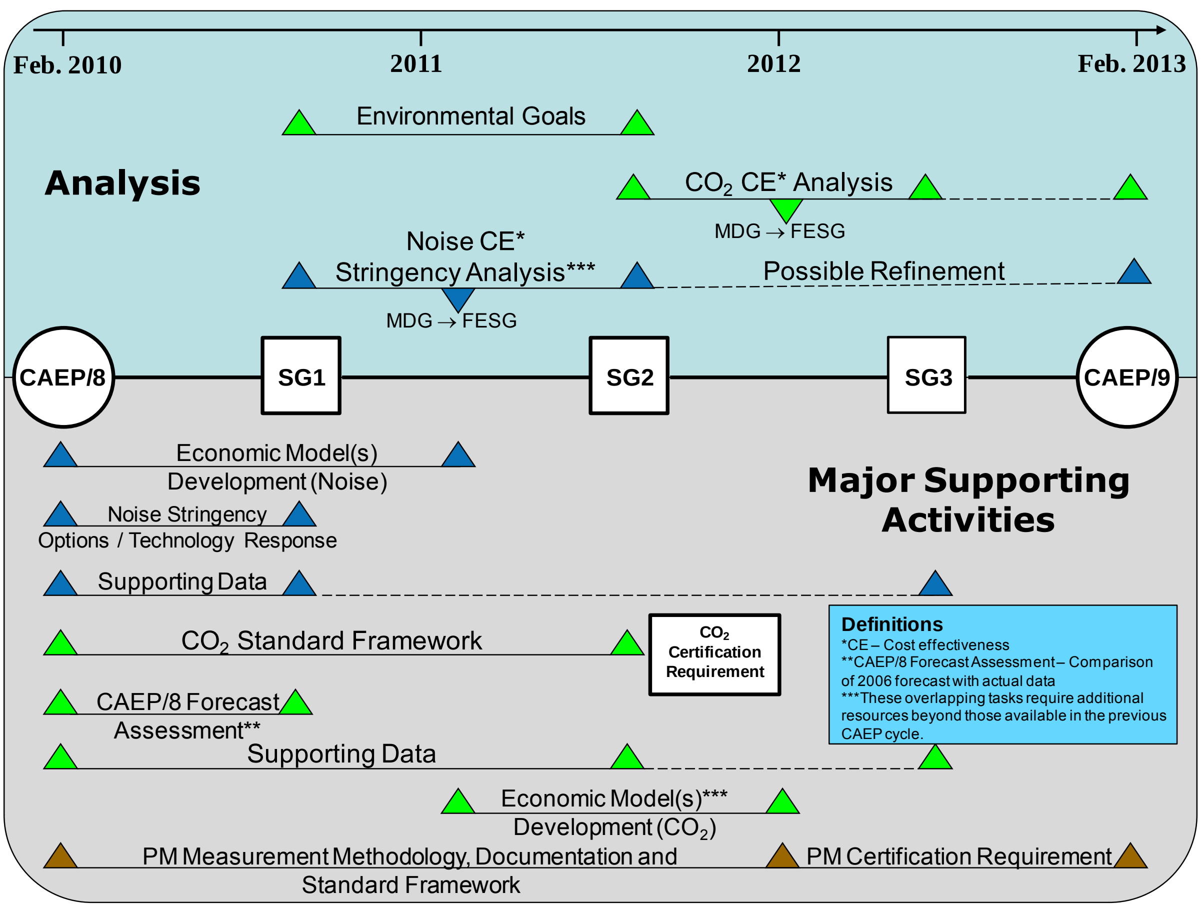


Figure 1

5.7.2 Figure 1 represents a potential high-level schedule for the CAEP /9 analysis. A detailed description of that schedule is shown in Appendix I.

5.8 CALENDAR

5.8.1 The meeting agreed to hold the following Steering Group meetings prior to CAEP/9:

a) Toulouse, France, 8 to 12 November 2010;

b) Beijing, China, 12 to 16 September 2011; and

c) TBD, Russian Federation, 18 to 22 June 2012.

5.8.2 The full calendar leading to CAEP/9 will be agreed by the first Steering Group meeting.

5.9 CLOSING REMARKS

5.9.1 In her closing remarks, the Secretary thanked the meeting for their dedication to the work of CAEP. She congratulated the members and observers for the true spirit of cooperation present throughout the meeting to achieving consensus and for the development of a future work programme that will meet the needs of the Organization.

5.9.2 The First Vice President of the Council thanked CAEP for its support to ICAO and the Council on the organization's strategic objective of environmental protection. He reminded the meeting of the value of their work and wished the committee success during the upcoming CAEP cycle.

5.9.3 The Chair also thanked CAEP members and observers for their diligent efforts and formally closed the meeting.

— — — — — — — —

CAEP/9 Working Group 1 Work Programme

Members: ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, ICCAIA, Italy, Spain, Japan, Nigeria, Russian Federation, UK, USA, Secretariat

Project Number	Short Title	Description	Target Date	Deliverable	Support
N.01.01	COORDINATION: Technology, operations and goals coordination	Coordinate with other working group Rapporteurs on interdependencies related to technology, operational issues, and goals as well as harmonizing the goal setting process	Ongoing	Coordination	Rapporteurs
N.01.02	COORDINATION: Databases coordination	Coordinate with other working group Rapporteurs on interdependencies related to management and update of noise and emissions databases	Ongoing	Coordination	Rapporteurs
N.01.03	COORDINATION: Environ-mental impacts coordination	Coordinate with other working group Rapporteurs on interdependencies related to environmental impacts, including stringency	Ongoing	Coordination	Rapporteurs
N.01.04	COORDINATION: SST coordination	Coordinate with other working group Rapporteurs on programmes for development of both noise and emissions SARPs for future supersonic aeroplanes	Ongoing	Coordination	Rapporteurs
N.02	Technical issues	Maintain and update Annex 16 Volume I and ETM Volume I	CAEP/9	Proposed changes to Annex 16 Volume I and ETM Volume I	All WG1
N.03	NoisedB	Ensure process integrity and data currency of the ICAO noise certification database	Each WG1 meeting	Up-to-date ICAO NoisedB	All WG1
N.04.01	TECHNOLOGY: Monitor research	Monitor and report on the various national and international research programme goals and milestones	SG3	Report	All WG1
N.04.02	TECHNOLOGY: Technology goals bench-marking	Review progress towards achievement of Technology Goals recommended by IEs for 2018 and 2028.	SG3	Report	All WG1
N.04.03	TECHNOLOGY: new technology	Using the IE process conduct review of new technological advances (e.g., open rotor, geared turbofan, blended wing body, etc.)	Spring 2012 WG1 meeting	Report	All WG1
N.04.04	TECHNOLOGY: Liaise with other IERs	Build upon work done for other IE reviews	Spring 2012 WG1 meeting	Report	All WG1

Project Number	Short Title	Description	Target Date	Deliverable	Support
N.04.05	TECHNOLOGY: IER alignment	Develop common approach on "Realization Factor" and uncertainty estimation for goal setting as well as align goal dates (2020 and 2030)	Spring 2012 WG1 meeting	Report	All WG1
N.05.01	SUPERSONIC: SST standards	Investigate adoption of current subsonic noise rules for supersonic Standards and make recommendations as appropriate	SG3	Report and, if approp-riate, proposed changes to the Annex	All WG1
N.05.02	SUPERSONIC: SST monitoring	Monitor, and report on, status of SST projects and expectations for their operation (nature, frequency etc.)	CAEP/9	Report	All WG1
N.05.03	SUPERSONIC: Sonic boom research monitoring	Monitor and report on research to characterize, quantify and measure (including metric) sonic boom signatures and their acceptability while also assisting in promoting and defining such research. Assess the extent of knowledge on sonic boom and decide if it is appropriate to consider drafting Standards for sonic boom.	CAEP/9	Report	All WG1
N.06.01	STANDARDS: Stringency option development	Review and analyze certification noise levels for subsonic jet and heavy propeller-driven aeroplanes. This work will include review of BP database application and content. Based on the analysis, develop a range of stringency options up to 10-12 dB cumulative margin relative to Chapter 4. The stringency options should take into account the margins at each of the 3 certification points. The stringency options shall apply to new aircraft types only, starting 1 Jan 2017 to 1 Jan 2020. No phase out of aircraft should be considered as part of the options investigated. The options considered for the analysis should anticipate more information on new technologies by the end of the CAEP/9 cycle. Other options can be considered following SG1 based on data availability. Any subsequent recommendation should not preclude low carbon technology such as the open rotor.	SG1	Report on stringency options and technology response (market impacts of regulatory levels is product of cost-effectiveness analysis conducted by MDG and FESG)	All WG1
N.06.02	STANDARDS: Interdependencies	Coordinate with WG3 to assess interdependency effects of noise stringency options with respect to CO_2/fuel burn and NOx.	SG1 and when WG3 has provided request	Interdependency effects	All WG1

Project Number	Short Title	Description	Target Date	Deliverable	Support
N.06.03	STANDARDS: Interdependencies	Respond to WG3 requests to assess interdependency effects of CO_2 emissions stringency options with respect to noise.	SG1 and when WG3 has provided request	Interdependency effects	All WG1
N.06.04	STANDARDS: Growth and replacement database	Review and update the Growth and Replacement (G&R) database for stringency analysis by MDG and FESG. Coordinate with WG3 to ensure consistency in assumptions.	every SG	up-to-date G&R database	All WG1
N.06.05	STANDARDS: emerging technologies	Review data on emerging technologies.	CAEP/9	supplement to Report in N.06.01	All WG1
N.06.06	STANDARDS: Open rotor	Investigate methodologies for noise certification of aircraft with new engine concepts such as open-rotor, etc.	CAEP/9	Report	All WG1

– – – – – – – – – – – –

CAEP/9 Working Group 2 Work Programme

Project Number	Short Title	Description	Target date	Deliverable	Support
O.01.01	Independent Expert Operational Goals review	Using the IE process, carry out a robust Air Traffic Operational review (as outlined Appendix H), and make recommendations for operational goals for noise and fuel burn in the mid term (10 years) and the long term (20 years), using information and results from the limited CAEP/8 review, following a process similar to those of WG1 and 3, and addressing issues identified at SG/2009 and in the CAEP/8 IE report.	see O.01.02 and O.01.03	see O.01.02 and O.01.03	All WG2 Members
O.01.02	Independent Expert Operational Goals review (Action Plan)	Develop an action plan and schedule (based on Appendix H) for addressing issues raised by CAEP/SG and IEs, and conducting a more robust IE process	SG 2010	Action plan and schedule for addressing issues raised by CAEP/SG and IEs, and conducting a more robust IE process	All WG2 Members
O.01.03	Independent Expert Operational Goals review (Report)	Facilitate an IE review including: a) Generate the guidance, information and material needed for the IE process; b) Hold a workshop and the IE Review; c) Hold follow-on meetings and regular telecons with the IEs to facilitate IE assessment and formulation of findings and report. This could involve providing additional information to the IEs. This task will include harmonising the processes and planning (e.g., base year) for operational goal setting with other IE processes to the extent possible.	SG 2012	IE Report on recommendations for noise and fuel burn with respect to air traffic operational goals in the mid term (10 years) and the long term (20 years)	All WG2 Members

Project Number	Short Title	Description	Target date	Deliverable	Support
O.02.01	Operational Opportunities to reduce fuel burn and emissions GM (Initial Chapters)	Refine the 4 draft chapters submitted to CAEP/8 (Chapter 2 - Airport Operations, Chapter 6 - Air Traffic Management, Chapter 7 - Non-Revenue Flying, and Chapter 12 - The Effect of Load Factor on Fuel Efficiency) to address outstanding comments and ensure the documents are harmonized with other ICAO provisions and industry best practices	Aim for SG 2010	4 Completed Chapters for SG approval (Note: These chapters will not be publically available until the document is complete)	All WG2 Members
O.02.02	Operational Opportunities to reduce fuel burn and emissions GM (Completion)	Complete updates to the Circular 303 guidance material initially via the ad hoc group approach utilized at the end of the CAEP/8 work cycle. This task will include informally briefing the ANC on progress.	SG 2012	Completed draft final guidance material for SG approval	All WG2 Members
O.03.01	CNS/ATM Environmental Assessment High-Level Principles (Program Plan)	Draft a Program Plan to develop CNS/ATM environmental assessment guidance material. The plan should include compiling information on environmental assessment current best practices and identifying high-level principles to inform States, airports, ANSPs, and others.	SG 2010	Program Plan	All WG2 Members + Australia

Project Number	Short Title	Description	Target date	Deliverable	Support
O.03.02	CNS/ATM Environmental Assessment High-Level Principles (Guidance)	Develop CNS/ATM environmental assessment guidance material by compiling information on environmental assessment current best practices and identifying high-level principles to inform States, airports, ANSPs, and others. The task will be focused in scope on environmental impacts assessment (including both engine emissions and noise) related to proposed operational procedures changes, airspace redesigns, and other similar operational aspects. a) The task will develop approach/methodology and metrics coherently, rather than treating them as separate guidance tasks as in CAEP/8; b) The principles must be high-level and flexible to account for state-specific requirements and needs with respect to methodologies and metrics; c) The best practices should be requested directly from ANSPs and others as appropriate for use in developing the guidance material; d) The high-level principles will seek to identify information to populate proposed metrics and/or to validate or apply assessment methodologies	SG 2012	Guidance material	All WG2 Members + Australia
O.04	Task Coordination	The "operations" tasks will be coordinated within CAEP as necessary (e.g., WG1, WG3, MDG, FESG), Secretariat, external expert groups (e.g., CANSO), and external international initiatives (e.g., AIRE, ASPIRE). Liaisons from these groups will be encouraged to participate.	Ongoing	Coordination	All WG2 Members

– – – – – – – – – – – –

CAEP/9 Working Group 3 Work Programme

Members: ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Italy, Japan, Netherlands, Nigeria, Russian Federation, Singapore, Spain, Sweden, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.01	Interdependencies	Co-ordinate with other working group Rapporteurs on interdependencies related to (a) technology, operational issues and goals (b) management and update of noise and emissions databases (c) environmental impacts (d) SARPs for future SST aircraft.	Ongoing	Coordination report for each SG	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat
E.02	Technology Goal: Fuel Burn	Using the IE process, carry out a Fuel Burn Improvement Technology review and make recommendations for technology goals and any necessary metric for timelines to be consistent with other working groups and UNFCCC	SG2010	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.03	Technology Goal: NOx	Dependent on demonstrable need and available resources, using the IE process, review progress towards achievement of NOx Technology Goals already set for 2016 and 2026; and, if requested, make recommendations for technology goals for timelines to be consistent with other working groups and UNFCCC.	CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.04	Fuel Efficiency metrics (Fleet level)	Continue scoping and development of fuel/CO2 efficiency metrics for specific application to CAEP work, including business aircraft, including the GIACC "Net CO2 Intensity Metric" and the CASFE metric	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat
E.05	Alternative fuels & emissions	Examine and report on the emissions consequences resulting from the use of alternative fuels for aviation [both 'drop-in' replacements and 'non-drop-in']. Does not include lifecycle CO2 emissions.	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.06	Fuel composition & emissions	Monitor trends in aviation kerosene fuel supply composition and assess consequences for emissions.	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.07	Technology advances	Provide assessment of advances in aircraft and engine design technologies for subsonic aircraft and the degree to which these technologies could influence gaseous emissions, smoke, particulate matter and fuel consumption; including the potential benefits and trade-offs amongst various emissions and noise, the likely timescales for introduction.	CAEP/9	a stand-alone report or as part of a goal review.	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.08.01	CO2 - Emission Standard (aircraft)	Conduct broad analysis to develop metric and methodology for a certification requirement pertaining to an aircraft CO_2 emissions standard.	CAEP/9 SG2011	Certification requirement	ACI, Brazil, Canada, China, EC, Egypt, Germany, IATA, ICCAIA, ICSA, Italy, Japan, Netherlands, Singapore, Spain, Sweden, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.08.02	CO2 - Emission Standard (aircraft)	Develop stringency proposals, including technology responses, regulatory levels and applicability and dates for evaluation of cost effectiveness and market impacts by FESG and MDG	CAEP9	Inputs for Cost effectiveness analysis	ACI, Brazil, Canada, China, EC, Egypt, Germany, IATA, ICCAIA, ICSA, Italy, Japan, Netherlands, Singapore, Spain, Sweden, UK, USA, Secretariat
E.08.03	CO2 - Emission Standard (aircraft)	Recommend an aircraft CO_2 emissions standard including applicability	Aiming for 2013, adjusting programme plans as necessary to ensure quality and effectiveness	Aircraft CO_2 emissions standard	ACI, Brazil, Canada, China, EC, Egypt, Germany, IATA, ICCAIA, ICSA, Italy, Japan, Netherlands, Singapore, Spain, Sweden, UK, USA, Secretariat
E.09	Interdependencies	Coordinate with WG1 to assess interdependency effects of CO2 emissions stringency options with respect to noise	As required	Assessments as needed	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.10	Interdependencies	Respond to WG1 requests to assess interdependency effects of noise stringency options with respect to CO2/fuel burn and NOx	As required	Assessments as needed	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat
E.11	Annex 16, Vol. II maintenance	Maintain Annex 16, Volume II, taking account of updates to SAE-E31 documentation	CAEP/9	Proposed Annex changes	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.12	ETM maintenance	Maintain the emissions Environmental Technical Manual;	CAEP/9	Proposed ETM changes	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.13	Emissions Database maintenance	Maintain the ICAO engine emissions certification databank.	on-going	up-to-date databank	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.14	G&R database maintenance	Review and update a "Growth & Replacement" database in order to support development of models used to populate future fleets and the replacement of retired aircraft. Coordinate with noise group to ensure consistency in assumptions.	During CAEP/9	up-to-date G&R databank	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat
E.15.01	NOx cruise - Climb relationship	Review the LTO NOx - cruise climb NOx relationship for staged combustion technologies, to quantify control of mission emissions of NOx, and identify any methodology issues with respect to the correlation between LTO and climb/cruise.	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.15.02		In addition monitor the need for the possible further development of the LTO NOx - cruise climb relationship for other future engine technologies to quantify control of mission emissions of NOx			ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat
E.16	Certification Requirements - SST	Review and revise as appropriate the existing methodology and requirements for supersonic aircraft engine certification	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat
E.17	Certification requirements - new engine concepts	Develop methodologies for emissions certification of new engine concepts such as open-rotor, etc	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Russian Federation, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.18.01	PM - Non-volatile	Evaluate and document sampling and measurement methodologies for aircraft engine non-volatile PM emissions. Note input from SAE-E31	CAEP/9	Certification requirement	
E.18.02		Develop an aircraft engine based metric and methodology for application as a non-volatile PM emissions certification requirement for new engine types.			ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
E.19	PM - volatiles	Evaluate and document sampling and measurement techniques to characterise the formation of volatile PM; Note input from SAE-E31	During CAEP/9	Report	ACI, Brazil, Canada, China, EC, Egypt, France, Germany, IATA, IBAC, ICCAIA, ICSA, Japan, Nigeria, Switzerland, UK, USA, Secretariat

- - - - - - - - - - - -

CAEP/9 FESG Work Programme

Members: ACI, Brazil, Canada, EC, Germany, IATA, ICCAIA, ICSA, Netherlands, Nigeria, Norway, Singapore, Spain, Switzerland, UK, USA, Secretariat

Project Number	Short Title	Description	Target date	Deliverable	Support
F.01	Review of Economic Models	Review of economic models as needed for the CAEP/9 analyses	During CAEP/9	Report	All FESG Members
F.02	Cost-effectiveness analysis of potential noise stringency options	Cost-effectiveness, including impacts on passengers, airports, airlines, etc., analysis of potential noise stringency options under consideration for CAEP/9	During CAEP/9	Report	All FESG Members
F.03	Cost-effectiveness analysis of potential CO_2 policy options	Cost-effectiveness analysis of potential CO_2 policy options under consideration for CAEP/9	During CAEP/9	Report	All FESG Members
F.04	Review of FESG CAEP/8 forecast	Conduct a comparison of the CAEP/8 forecast with actual data	SG1	Report	All FESG Members
F.05	Assessment of the potential impact of constraints	Conduct a study on the potential impact of constraints on forecasting results	During CAEP/9	Report	All FESG Members + MDG

— — — — — — — — — — — —

CAEP/9 MDG Work Programme

Members: ACI, Brazil, Canada, EC, France, Germany, IATA, ICCAIA, ICSA, Japan, Netherlands, Russian Federation, Spain, Switzerland, UK, Ukraine, USA, Secretariat

Item Number	Short Title	Description	Target date	Deliverable	Support
M.01	Interdependencies	Coordinate with other working group Rapporteurs on interdependencies related to technology, operational issues, goals, environmental impacts and management and update of noise and emissions databases.	Ongoing	Coordination	All MDG
M.02	Noise Stringency	Conduct policy option analyses of the environmental benefits and interdependencies of a potential noise stringency as directed by CAEP and SG.	CAEP/9	Report on policy option analyses results	All MDG
M.03	CO_2 Standard	Conduct policy option analyses of the environmental benefits and interdependencies of a potential CO2 standard as directed by CAEP and SG.	CAEP/9	Report on policy option analyses results	All MDG
M.04	ICAO Environmental Goals Assessment	To support ICAO Environmental Goals and HLM Recommendation 9, conduct an updated GHG assessment, for the baseline case (both 2005 and 2006) and forecasts, and for various cases which consider technology and operational improvements. Assemble available data on alternative fuels life cycle for consideration in the CAEP/9 assessment.	During CAEP/9	Report on fuel burn, fuel efficiency and CO2 trends	All MDG
M.05	Model and database management	Model and Database management. Maintain version control of models and databases to be used in support of specific CAEP analyses. Determine if updates to models or databases require a re-evaluation. Model evaluation may now include dispersion and consideration of particulate matter.	During CAEP/9	List of model and database versions	All MDG
M.06	Summarize Capabilities	If new models are introduced to support CAEP/9, continue the candidate model evaluation process initiated in the previous work program, which calls for sensitivity tests, comparisons with “gold standard data, and sample problems. Refine the process as appropriate on the basis of relevant criteria, to better inform CAEP which tools are sufficiently robust, rigorous and transparent, and appropriate for which analysis, and why there might be differences in modelling results.	During CAEP/9	Report	All MDG

Item Number	Short Title	Description	Target date	Deliverable	Support
M.07	Updated Databases	Working with the appropriate working groups, develop updated databases, as required	By Steering Group 2	Databases	All MDG
M.08	Document 9911	Review and update ICAO Document 9911, as appropriate.	CAEP/9	Report	All MDG
M.09	Fuel Burn Reporting	Seek to improve modelling and State reporting of fuel burn data by conducting a comparitive assessment of modelled and reported data, as reported data becomes available.	CAEP/9	Report	All MDG
M.10	CAEP Support	Provide support to CAEP Secretariat in dissemination of MDG results.	CAEP/9	As Required	All MDG
M.11	LAQ Guidance	Finalize the mitigation and interdependencies chapters of the air quality guidance manual.	By Steering Group 1	Report	All MDG

— — — — — — — — — — — —

CAEP/9 ISG Work Programme

Members: Dr. Lourdes Maurice and Prof. David Lee. Additional scientific experts to be nominated following the finalization of the Terms of Reference. The following CAEP members and observers have offered their support, subject to nomiation: ACI, Brazil, Canada, IATA, ICCAIA, Norway, UK, USA

Project number	Short Title	Description	Target date	Deliverable	Support
I.01.01	Coordination (internal group)	Coordination on activities	Ongoing	Coordination	FAA (LM), UK (MMU, DSL)
I.01.02	Coordination (internal ICAO)	Coordination with other WGs, TFs, RFPs, etc. Rapporteurs and Secretariat on activities	Ongoing	Coordination	FAA (LM), UK (MMU, DSL), WG Rapps, Sec.
I.01.03	Coordination (external)	Consultation with experts from external agencies (e.g. WHO, WMO, IPCC, UNFCCC, etc.)	Ongoing	Consultation	Principally FAA (LM), UK (MMU, DSL), Also relevant core science impacts experts
I.02.01	Group task development	Review CAEP work programme and identify critical science needs	SG1 to 3	WP to SG	FAA (LM), UK (MMU, DSL), relevant core science impacts experts
I.02.02	Group task development	Review with co-rapps on implementation possibilities arising from Impacts Workshop	SG1	WP to SG1	FAA (LM), UK (MMU, DSL), WG Rapps, Workshop clim, AQ, noise, interdependencies co-chairs

I.02.03	Group task development	Development of TORs, modus operandi to clearly define the scope of the work programme of the ISG.	SG1	WP to SG1	FAA (LM), UK (MMU, DSL), WG Rapps, Workshop clim, AQ, noise, interdependencies co-chairs
I.03.01	Climate context (CO_2)	Development of unerlying science thinking on aviation within context of UNFCCC discussions and other national/regional climate initatives to inform ICAO-CAEP	SG2	WP to SG2	FAA (LM), UK (MMU, DSL), relevant core science impacts experts
I.03.02	Climate context (non-CO_2)	Coordination of non-CO2 issues for consensus science to inform ICAO-CAEP	SG2, 3	WPs to SG2, SG3	FAA (LM), UK (MMU, DSL), relevant core science impacts experts
I.03.03	Local and surface air quality context	Development of thinking on aviation impacts and relevance to CAEP activities	SG2, 3	WPs to SG2, SG3	FAA (LM), UK (MMU, DSL), relevant core science impacts experts
I.03.04	Noise context	Development of thinking on aviation impacts and relevance to CAEP activities	SG2, 3	WPs to SG2, SG3	FAA (LM), UK (MMU, DSL), relevant core science impacts experts
I.03.05	Interdependencies context	Development of thinking on aviation impacts and relevance to CAEP activities	SG2, 3	WPs to SG2, SG3	FAA (LM), UK (MMU, DSL), relevant core science impacts experts

— — — — — — — — — — — —

CAEP/9 ACCS Work Programme

Members: Australia, Brazil, Canada, IATA, ICCAIA, ICSA, Poland, Sweden, Secretariat

Project number	Short Title	Description	Target date	Deliverable	Support
C.01	ICAO Fuel Consumption Form	Provide CAEP comment and recommendations on the proposed fuel data collection form	Mar-10	Report and recommendations to the Statistics Division	All members
C.02	Enhancements to passenger Carbon Calculator	Refine the methodology and database associated with the passenger Calculator by (a) updating the current database (b) updating the methodology and underlying data sources using flight level global emissions inventories generated by AEDT/SAGE, AEM III, Aero 2k and FAST, and (c) transiting from modelled to measured values using measured fuel consumption data at the city pair level from industry bodies.	During CAEP/9	Enhancements to Carbon Calculator	All members
C.03	Estimating CO_2 emissions from air freight	Develop *Frequently Asked Questions* text for the ICAO website, on the difficulties of accurately estimating the CO_2 emissions attributable to air freight at this time. As a next step, develop a set of non-binding guidelines to enable interested parties to develop a carbon calculator methodology for belly freight.	During CAEP/9	Text and Guidelines for inclusion on ICAO website	All members
C.04	Explore ways to collect data on offsetting and its use	Report on ways in which ICAO could collect data on the quantity of offsetting associated with air travel and how such data would be used by ICAO.	SG2	Report	All members

— — — — — — — — — — — —

APPENDIX H

IEOGG WORK PROGRAMME

1. In conducting the CAEP/9 Revision of the air traffic operational goals review for fuel burn the following issues should be regarded:

a) a planning committee should be established as soon as possible to perform the duties identified in the schedule below. This will include opportunities to seek new experts, addressing limitations outlined by IEs and SG, and stronger facilitation of the process;

b) a proposed scope will be developed by the CAEP/9 planning committee consulting as required interested State and Observer experts, and presented at the first SG, to advise the IEs;

c) the planning committee should review documentation on WG1 and 3 IE processes and lessons learned, coordinate with WG1 and 3 Rapporteurs for additional process details, and outline a consistent approach, updating terms of reference as needed, for presentation at the first SG. This will include possibilities for new experts to join the CAEP/9 IE review;

d) the CAEP/8 IEOGG report and results will not be made widely or publically available. The report and results will be used as an initiating point for a more thorough review in CAEP/9.

e) Additional information sources will be considered as part of the more robust IE process in CAEP/9;

f) when re-performing the IE process in CAEP/9 (using an expanded timescale, scope, expert base, etc), the IEs should facilitate the estimation of the potential reduction of noise exposure from ATM improvements;

g) planning committee will review information needs, priorities, implications of gaps and provide a roadmap to propose a way forward to working arrangements and possibly to CAEP/9 1st SG. Related CAEP tasks developing high-level principles for assessment methodology and metrics may inform the goal setting process; and

h) regarding membership:

   1) the Planning Committee should reconsider IE membership taking into account the WG1 and WG3 IE member selection process, and if necessary reconstitute IE group; and

2) regardless of outcome of #1, distribute a new State and Observer letter during CAEP/9 to invite nomination of additional experts to participate in the CAEP/9 IE Review.

2. A potential schedule for the planning committee is listed below, based on the approach and schedule utilized by WG1 during CAEP/8. This should be revisited and refined by the CAEP/9 planning committee.

a) Convene a planning committee (including States, airlines, manufacturers, ANSPs, etc) to manage the IE process as soon as feasible after CAEP/8. A key topic for discussion will be the proposed scope of 'Operations' for the IE work – with a view to agreeing this as soon as is practicable.

b) Develop an action plan and schedule for addressing issues raised by CAEP/SG and IEs, and conducting a more robust IE process.

1) seeking advice and lessons learned from WG1, WG2, MODTF and others (for expected outputs);

2) revisit TOR and revise as necessary;

3) re-evaluate membership of IE group;

4) develop updated invitation to States and Observers for nomination of IEs

5) develop a proposed Scope for 'Operations' and to clarify the internal and external uses to which the IE deliverables will be put; and

6) present at first SG.

c) Generate the guidance, information and material needed for the IE process.

d) Hold a workshop and the IE Review

e) Hold follow-up meetings and regular telecons with the IEs to facilitate IE assessment and formulation of findings and report. This could involve providing additional information to the IEs; and

f) Deliver a report and recommendations to CAEP/9.

3. The objectives of the proposed activities are:

a) update the Initial Operational Goals report that has been submitted to CAEP/8 (Montreal Feb 2010); to a standard that addresses SG Salvador concerns;

b) independently provide Operational Goals of sufficient robustness to allow their publication for uses to be determined and to support modelling of forecast impacts for CAEP decision making;

c) ensure clarity of purpose and scope and that CAEP needs are fully met;

d) set a framework for the consistent iteration of these independent operational goal setting activities; and

e) harmonize the processes and planning for operational goal setting with other Independent Expert (IE) processes to the extent possible.

— — — — — — — —

APPENDIX I

POTENTIAL HIGH-LEVEL SCHEDULE FOR CAEP/9 ANALYSES

1. The CAEP/9 Work Programme has the potential to be very labor intensive, and results could become difficult to achieve, if CAEP does not agree on expectations and hold strictly to priorities.

2. All of the Work Programme priorities have implications on Working Group (WG) 1, WG 3, the Modelling and Databases Group (MDG) and the Forecasting and Economics analysis Support Group (FESG). These priorities will likely lead to at least three major analyses: (1) an aircraft CO_2 emissions standard; (2) an update of the environmental goals; and (3) a noise stringency.[1] To ensure that all three major analyses can be completed within the current CAEP/9 Work Programme, it is essential that CAEP agree to a strict schedule which includes basic underlying assumptions and comprehensive coordination across the four groups and that Member States and Observers make firm commitments to volunteer resources in support of these analyses. This work cannot be conducted in a sequential manner since all groups need to be engaged throughout the process. In addition, the analyses must be staggered in time and cannot be conducted simultaneously due to resource limitations.

Schedule and assumptions

3. Figure 1 is a proposed high-level schedule for accomplishing the potential CAEP/9 analyses. It shows the three main analyses in the top half along with major support activities in the bottom half, and the recognition of possible work related to PM, also in the bottom half. The analyses in the top half are linked with their accompanying supporting activities using color coding, either blue or green. The analyses are shown as discrete tasks, but practically this is not the case. For example, any work on noise stringency scoping and fuel burn technology goals will likely have a direct relationship on the CO_2 standard. This adds a level of complexity and risk to the work programme which is not easily captured in a simple schedule, but this added risk must be taken into account when resources are being considered by CAEP in support of the various working groups. In addition, while the timelines show well-defined start/stop points for each task, in reality substantial iteration between the groups will be required around each task's start/stop points. It is critical that the four groups have early and frequent engagement. Some additional thoughts on facilitating coordination are presented in Section 3.

4. The highest priority task for the CAEP/9 Work Programme is an aircraft CO_2 emissions standard. Given the novel and high-visibility nature of a CO_2 standard, preparatory work would need to begin immediately. The schedule presented in Figure 1 calls for a completed certification requirement ready for the second CAEP/9 SG meeting. WG3 will likely lead the development of the framework underlying the requirement, but would require substantial liaison with WG1 (noise tradeoffs), MDG (environmental benefits) and FESG (cost benefits). The primary elements of the requirement would consist of:

[1] Analysis support for a potential particulate matter (PM) certification requirement and standard as well as a possible market-based measures analysis are also possible, but not considered in detail herein. While PM is cited as a possibility in the presented schedule, these two areas of potential analysis are better addressed at a future meeting of the CAEP SG, as needed.

a) agreement on scope and applicability (e.g., definition of standard mission, maximum takeoff weight threshold and airframes covered);

b) definition of the metric procedure and measurement methodology (e.g., certification requirement);

c) assessment of voluntary initial data from manufacturers;

d) agreement on parameters to be reported under the certification requirement; and

e) process for collecting and assessing data via mandatory compliance under Member State's promulgation of the requirement into national laws.

5. Subsequent to the agreement on the certification requirement at the second SG meeting, ICAO would need to initiate actions for adoption of the recommended CO_2 requirement which would also be incorporated into Member State legislation. Manufacturers would then be in a position to apply for their aircraft types to be certified by Aviation Authorities against this requirement. Ways to accelerate this adoption process should be considered in order to facilitate the formal certification of aircraft types against the agreed CO_2 requirement. The publication of certified aircraft CO_2 data is considered to be beneficial in itself.

6. Simultaneous with the formal adoption of the certification requirement, WG3 should work to develop the potential stringency options and the technology responses, including future years to be analyzed and NOx and noise tradeoffs, working with WG1, as appropriate. The result of this WG3 activity would be provided to MDG and FESG to conduct an associated cost effectiveness assessment. Depending upon the timing of a comprehensive set of manufacturers' data the subsequent MDG and FESG analysis would either serve as a sample problem or a full CO_2 standard stringency assessment. The analysis of a CO_2 standard would be based on the existing 2006 MDG Common Operations Database (COD) and the FESG CAEP/8 forecast, i.e., no new baseline operations data or forecast would be required. This schedule would also allow MDG and FESG working closely with WG1 and WG3 to anticipate and establish collective ownership of the framework in advance of the second CAEP SG meeting. This would permit MDG and FESG to investigate, scope and prepare their models for a successful analysis. MDG would need to have their tools and databases ready for the second CAEP SG, while FESG would need to have its economic analysis tool(s) ready for just after the second CAEP SG meeting.

7. It is anticipated that the environmental goals analysis would require the least resources of the three planned analyses. It is currently anticipated that an updated FESG forecast would not be required for the CAEP/9 goals assessment, but rather a comparison of the CAEP/8 forecast with actual data should be undertaken. This comparison would be used to inform an updated environmental goals assessment. Given the comprehensive nature of the CAEP/8 goals assessment and the close agreement with CAEP/7 results, it is recommended that this simpler approach to environmental goals be undertaken, one which focuses primarily on global fuel burn. If needed for the environmental goals analysis, the CAEP/8 future technology and operational improvement trends should be used, as WG1 and WG3 will likely not have the resources to update this information, and any changes are expected to be small.

8. To minimize overlap with the highest-priority aircraft CO_2 emissions standard analysis discussed in Section 2.2, preparatory work for a noise stringency would need to begin immediately in the CAEP/9 work cycle, leading to a defined framework (e.g., stringency options, technology responses) by

the first CAEP SG meeting. An important caveat is the need for manufacturers' noise data for aircraft expected to enter into service by the earliest agreed-upon applicability date as well as new-technology engines (e.g., open rotor and geared turbo fan). Should all necessary data be unavailable by the first CAEP/9 Steering Group meeting, further analysis will be needed after the second Steering Group meeting, as illustrated by the dashed line in Figure 1. WG1 would have the lead on this effort, but would require substantial liaison with WG3 (NOx and fuel burn tradeoffs[2]), MDG (environmental benefits) and FESG (costs). The primary elements of the framework would consist of:

a) scope of airframes covered;

b) stringency options (cumulative and/or per certification point levels) and technology response to be analyzed;

c) NOx and fuel burn tradeoffs; and

d) ground rules and assumptions to be considered in the cost and benefit analyses.

9. One underlying assumption we propose for a noise stringency analysis is that it be based on the existing 2006 MDG COD and the FESG CAEP/8 forecast. Therefore, no new baseline operations data or forecast would be needed since the noise stringency scoping would focus on the benefits of Policy A versus B, versus absolute benefits. This should allow MDG and FESG to prepare their models in time for a successful analysis. FESG would need to have its economic analysis tool for noise ready for just after the first CAEP SG meeting. It could either be based on the CAEP/5 methodology, or if sufficient time and resources are provided to FESG on an updated or new methodology.

10. Given the priority of CO_2 standard work, it is important to note that after the second CAEP/9 Steering Group meeting, unique resources that may be needed for both the CO_2 standard and follow-on noise stringency analysis identified will be prioritized in favour of the CO_2 standard work. Therefore, availability of resources may delay completion of the follow-on noise stringency analysis beyond the second Steering Group meeting.

Coordination

11. Figure 1 and the descriptions above focus on the *major* support activities for each of the three planned CAEP/9 analyses. There are a number of additional, less-resource-intensive activities that cut across WG1, WG3, MDG and FESG but which are critical to the success of these analyses. They include updates to the ICAO Noise and Emissions Certification Database, Growth and Replacements Database, the Campbell-Hill/Campbell-Hill Extension Fleet Databases[3], and the Airports Database. To help ensure success, and given the breadth of the cross-cutting activities that support these three major analyses a more comprehensive coordination effort than has been used previously in CAEP should be considered for the CAEP/9 Work Programme.

12. During CAEP/8 a coordination plan was drafted for each CAEP SG to inform Members of any issues on which they needed to provide input. This coordination was accomplished primarily through the

[2] It is assumed that particulate matter (PM) tradeoffs would not be considered since there is insufficient knowledge on current aircraft engine PM emissions and how they would be affected by future technological responses.

[3] As part of the CAEP/8 Work Programme the fleet databases have been enhanced to include information on seats and maximum payload, which should help facilitate work in support of the CO_2 standard.

use of communication liaisons that would attend multiple meetings. This should continue in the CAEP/9 work cycle.

13. An important lesson learned from the CAEP/8 Work Programme is that passing along pre-requisite information /data from one CAEP group to another does not occur at a discrete point in time. In other words, the responsibilities of the originating group of the information are not complete after the information is passed along. It is essential to facilitate early and frequent engagement between the groups so that the passing along of information is an expected outcome and the receiver has ownership of the information.

14. In addition to designated liaisons between groups and reporting of coordination activities at the CAEP SG meetings, that the WGs consider co-located meetings or establishing cross-WG task groups if appropriate at points throughout the work cycle. In addition to resulting in better communication across the groups, this may result in limited resource savings as there are a number of individuals that attend multiple CAEP working group meetings.

— END —

ISBN 978-92-9231-588-7